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PROCEEDINGS
CONFERENCE ON
HAZARD EVALUATION AND RISK ANALYSIS

HOUSTON, TEXAS
18-19 AUGUST 1971

COMMITTEE ON
HAZARDOUS MATERIALS
Advisory to U. S.
Coast Guard

Divison of Chemistry
and Chemical Technology
National Research Council

NATIONAL ACADEMY
of SCIENCES
Washington, D. C.

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INTRODUCTORY REMARKS - Professor D. L. Katz, Chairman

I am Professor Donald Katz, and welcome you today to this, the eighth annual conference of the Committee on Hazardous Materials.

It is indeed a pleasure to return to Houston. The Committee profited by our 1966 conference here, and we have followed with much interest the various developments in the shipment of hazardous materials, with the Houston area always in mind.

For those of you who we have not had the pleasure of meeting previously, a few brief remarks about the background and interest of our Committee may be in order.

Since 1964, The National Academy of Sciences, in response to a request from the Commandant of the Coast Guard, has studied scientific and technical aspects of safety and public health in the transportation of dangerous commodities by water. Among the stated objectives have been the following:

(a) To define problem areas and predict future conditions which affect the lives and property of operating personnel and the public.

(b) To advise on research needs, sponsor supervised research where the specific expertise of the committee is deemed essential, and to evaluate research findings.

(c) To assist a Coast Guard special task group to develop further a hazard rating system for bulk dangerous cargoes and to assign suitable ratings to specific commodities.

(d) To advise on standards of safety which will adequately protect operating personnel and the public without unnecessary restrictions on industry.

These objectives have been served by a Committee on Hazardous Materials, Advisory to the U. S. Coast Guard, assisted by a full-time technical secretary on the Academy's staff. The present membership is before you, and we invite you to meet with them personally. Many additional scientists and engineers have participated in the conferences and task panels sponsored by the Committee. The Committee itself has met at approximately quarterly intervals, one session each year being devoted to a conference on a broad topic, to which a number of interested participants have been invited. Our last conference was held last July at the Coast Guard Academy in New London, Connecticut, and considered in depth the status of chemical reactivity and a review of information systems.

Our objective today and tomorrow is an in depth examination of systematic hazard analysis and risk evaluation, as well as a consideration of the ecological aspects of the Houston Ship Canal, Galveston Bay Area.

A word about our approach. We are a technically oriented group, which seeks to assist in problems by applying scientific and engineering principles. Our stated purpose is to advise the Department of Transportation, and specifically the Coast Guard, when they ask our opinions. In fact,

we also try to anticipate the problems which will be with us 5 or 10 years from now, so constructive steps can be taken in advance.

We cordially invite your comments, input, and reactions. Only by a full and truthful exchange of technical knowledge can we achieve our objectives and properly discharge our responsibilities.

In planning and arranging the many details which are required for this conference, our technical secretary, Mr. Fawcett, has received excellent cooperation from many persons. We especially acknowledge Mr. W. E. McConnaughey, who is our Coast Guard Liaison Officer, Captain W. E. West, Houston Captain of the Port, LTJG Herbert Hammon, III, his associate in hazardous materials and Captain D. F. Hall, Officer in Charge of Marine Inspection of Houston.

Welcome from CAPTAIN W. E. WEST, C.O.T.P.

Professor Katz, Committee Members and guests:

It is with great pleasure, both personally and in behalf of the Office of Captain of the Port of Houston, that we welcome you and your distinguished Committee to Houston. The work of your committee has been of highly significant value to the Coast Guard, and to us who are charged with day-by-day responsibility to insure the safety of the Port of Houston and the crews of ships. Hazardous materials play a very significant part in the Houston area. We hope your stay with us will be fruitful and worthwhile. My staff and I stand ready to assist you in whatever way we can during your conference, and we hope you will return often.

Welcome from CAPTAIN D. F. HALL, O.C.M.I.

Professor Katz, Committee Members and guests:

Captain West has expressed our pleasure at your selection of Houston for your 1971 conference. The Office in Charge of Marine Inspection, Houston, likewise is at your service, and we will be pleased to join you in working to our common objectives. God speed in your endeavors.

BENEFIT-COST STUDIES IN SOCIO-TECHNICAL SYSTEMS

Chauncey Starr
Dean, School of Engineering and Applied Science
University of California, Los Angeles

Introduction

The general problem of balancing utility versus total societal costs should be a part of all planning in our society. Traditionally, technical performance as a function of monetary cost is always involved in engineering design decisions. What we are discussing however is inclusion of all societal costs, indirect as well as direct, and all measures of utility, direct as well as indirect. Clearly, existent social-technical systems, over a period of many years, have developed an empirically acceptable balance between utility and social cost. In addition, we have examples of national decision making involving future social technical systems which contain implicit predictive trade-offs of societal benefits versus societal costs.

As the number of our socio-technical systems increase and their impact on the individual becomes more apparent, concern with achieving a planned balance of the utility of these systems against their societal costs has also increased. It has become apparent, therefore, that greater insight, analysis and predictive planning are essential for the future development of new or larger socio-technical systems.

These problems originate from certain general assumptions inherent in the operations of our society. First, it is traditionally accepted that everyone should have the opportunity for a natural death, that is, a death from old age, from a natural wearing out of the human body. Second, it is now commonly accepted that every individual should have the opportunity to use and enjoy the fruits of our centuries of technological development. Third, more recently we have emphasized our responsibility to assure for succeeding generations the best environmental and genetic inheritance that we can provide. And fourth, it is the philosophy of an egalitarian society that where the activities of an individual infringes on others in an undesirable way, the society may intervene to control individual activities in order to achieve a balance between group well-being and the privileges of the individual.

It is evident that these inherent basic assumptions are not fully compatible. Technology's contribution to enlarging the range of personal powers of the individual unfortunately also provides the individual with the power to damage others. In fact, the usual situation is that the benefits of technology are concentrated on the user, but the penalties are diffusely spread to many. Under these circumstances, the governing agencies of our society intervene and impose controls on both the individual and the technological system. Unfortunately, the criteria used by our society to achieve this balance of group and individual interests are rarely explicit, and are most often hidden in the complex empirical adjustments of our social, political, and economic subsystems.

We now face a general situation in which widespread use of a new technological development may occur before its social impact can be properly assessed, and before any empirical adjustment of the benefit-versus-cost relation is obviously indicated. It has been clear for some time that predictive technological assessments are a pressing societal need. However, even if such assessments become available, obtaining maximum social benefit at minimum cost also requires the establishment of a relative value system for the basic parameters in our objective of improved "quality of life." The empirical approach implicitly involved an intuitive societal balancing of such values. A predictive analytical approach will require an explicit scale of relative social values.

For example, if technological assessment of a new development predicts an increased per capita annual income of x percent but also predicts an associated annual per capita accident probability of y fatalities, then how are these to be compared in their effect on the "quality of life?" Because the penalties or risks to the public arising from a new development can be reduced by applying constraints, there will usually be a functional relationship (or trade-off) between utility and risk, the x and y of our example.

In order to provide insight to this problem of societal criteria for evaluating benefits versus costs, I undertook a study of a specific one of our social values — fatalities arising from socio-technological systems. A quantitative analysis has been made of accidental deaths arising from technological developments in public use. This analysis was used to develop some generalized understanding of the public's approach to this social balance. The initial results were published in Science, Vol. 165, p. 1232-38, 19 September 1969.

The analysis makes two assumptions. The first is that historical national accident records do contain consistent patterns of fatalities in the public use of technology. The second assumption is that such historically revealed social preferences and values are sufficiently enduring to permit their use for predictive purposes. We have evidence that these assumptions may not be adequate in all cases. Quite clearly in the technological trade-offs involving environmental pollution, historical data is not available. Nevertheless, in those areas where information has been available for a considerable time, the study is revealing.

There are many historical illustrations of such trade-off relationships that were empirically determined. For example, automobile and airplane safety have been continuously weighed by society against economic costs and operating performance. In these and other cases, the real trade-off process is actually one of dynamic adjustment, with the behavior of many portions of our social systems out of phase, due to the many separate "time constants" involved.

Readily available historical data on accidents and health, for a variety of public activities, provide an enticing stepping-stone to quantitative evaluation of this particular type of social cost. The social benefits arising from some of these activities can be roughly determined. On the assumption that in such historical situations a socially acceptable and essentially optimum trade-off of values is

being approached or has been achieved, we could say that any generalizations developed might then be used for predictive purposes. This approach could give a rough answer to the seemingly simple question "How safe is safe enough?" Because this methodology is based on historical data, it does not serve to distinguish what is "best" for society from what is "traditionally acceptable." It also does not establish cause-effect relationships - rather, only the observable results of the cumulative operations of our social system.

Voluntary and Involuntary Activities

Societal activities fall into two general categories - those in which the individual participates on a "voluntary" basis and those in which the participation is "involuntary," imposed by the society in which the individual lives. The process of empirical optimization of benefits and costs is fundamentally similar in the two cases - namely, a reversible exploration of available options - but the time required for empirical adjustments (the time constants of the system) and the criteria for optimization are quite different in the two situations.

In the case of "voluntary" activities, the individual uses his own value system to evaluate his experiences. Although his eventual trade-off may not be consciously or analytically determined, or based upon objective knowledge, it nevertheless is likely to represent, for that individual, a crude optimization appropriate to his value system. For example, an urban dweller may move to the suburbs because of a lower crime rate and better schools, at the cost of more time spent traveling on highways and a higher probability of accidents. If, subsequently, the traffic density increases, he may decide that the penalties are too great and move back to the city. Such an individual optimization process can be comparatively rapid (because the feedback of experience to the individual is rapid), so the statistical pattern for a large social group may be an important "real-time" indicator of societal trade-offs and values.

"Involuntary" activities differ in that the criteria and options are determined not by the individuals affected but by a controlling body. Such control may be in the hands of a government agency, a political entity, a leadership group, an assembly of authorities or "opinion-makers," or a combination of such bodies. Because of the complexity of large societies, only the control group is likely to be fully aware of all the criteria and options involved in their decision process. Further, the time required for feedback of the experience that results from the controlling decisions is likely to be very long. The feedback of cumulative individual experiences into societal communications channels (usually political or economic) is a slow process, as is the process of altering the planning of the control group. We have many examples of such "involuntary" activities, war being perhaps the most extreme case of the operational separation of the decision-making group from those most affected. Thus, the real-time pattern of societal trade-offs on "involuntary" activities must be considered in terms of the particular dynamics of approach to an acceptable balance of social values and costs. The historical trends in such activities may therefore be more significant indicators of social acceptability than the existent trade-offs are.

In examining the historical benefit-risk relationships for "involuntary" activities, it is important to recognize the perturbing role of public psychological acceptance of risk arising from the influence of authorities or dogma. Because in this situation the decision-making is separated from the affected individual, society has generally clothed many of its controlling groups in an almost impenetrable mantle of authority and of imputed wisdom. The public generally assumes that the decision-making process is based on a rational analysis of social benefit and social risk. While it often is, we have all seen after-the-fact examples of irrationality. It is important to omit such "witch doctor" situations in selecting examples of optimized "involuntary" activities, because in fact these situations typify only the initial stages of exploration of options.

The Continuum of Risk Exposure

Fatalities may arise from technological systems as either the result of discrete, statistical events, i.e., the true accident — or as a result of a continuous exposure to a cumulative hazard, i.e., environmental pollution. Although the distinction usually may be unimportant for an annual actuarial analysis —as in the case of motor vehicle deaths —both the societal and individual reaction to the risk is generally different. This is best illustrated by considering the extreme case of infrequent discrete catastrophes.

A tabulation of such catastrophes, both man-made and natural, are shown in Table 1. The frequency of events is very low, with a thousand-fold range of fatalities per event. If one excludes the people directly affected, the societal response to such a range of catastrophes is roughly uniform. The dramatic impact communicated by the news media (newspapers, radio, TV) is about the same for the crash of a large commercial airliner, the hurricane damage over a large territory, or the massive loss of life in an extreme earthquake.

It is likely that the very low frequency of such events tends to reduce their significance to the observer. The typical individual reaction is that these events are so rare both in time and location, that the consequent individual risk is negligible. So, the concept of "it will never happen to me" is easily accepted.

However, these infrequent catastrophes are generally the end-points of a continuous spectrum of like events, whose frequency increases exponentially as their individual severity decrease. The typical logarithmic relationship is shown in Figure 1, where the frequency and magnitudes of earthquakes are compared. The rapidly increasing frequency with diminishing severity of earthquakes begins to approach a steady series of tremors. The public awareness of this exposure is, of course, limited to the severe, infrequent earthquakes that do visible harm.

TABLE I

SINGLE EVENT MAJOR CATASTROPHES

TYPE OF EVENT	TIME PERIOD	MAGNITUDE (DEATHS/EVENT)			FREQUENCY EVENTS/YEAR
		Mode	Maximum	Average	
MAJOR AIR CRASHES	1965–1969	82	155	78	6.0
MAJOR AUTO CRASHES	1966	10	40	19	11.0
EARTHQUAKES	1920–1970	30,000	180,000	25,000	0.50
EXPLOSIONS	1950–1968	10	100	26	2.0
MAJOR FIRES	1960–1968	12	322	35	0.67
FLOOD, TIDAL WAVES	1887–1969	2,000	900,000	28,000	0.54
HURRICANES	1888–1969	400	11,000	1,105	0.41
MAJOR RAILROAD CRASHES	1950–1966	19	79	30	1.0
MAJOR MARINE ACCIDENTS	1965–1969	32	300	61	6.0
U.S. TORNADOS	1900–1969	72	689	78	0.74
TYPHOONS, CYCLONES, BLIZZARDS	1880–1970	10,000	300,000	37,240	0.18

MAGNITUDE DISTRIBUTION OF SHALLOW EARTHQUAKES
1904 - 1952

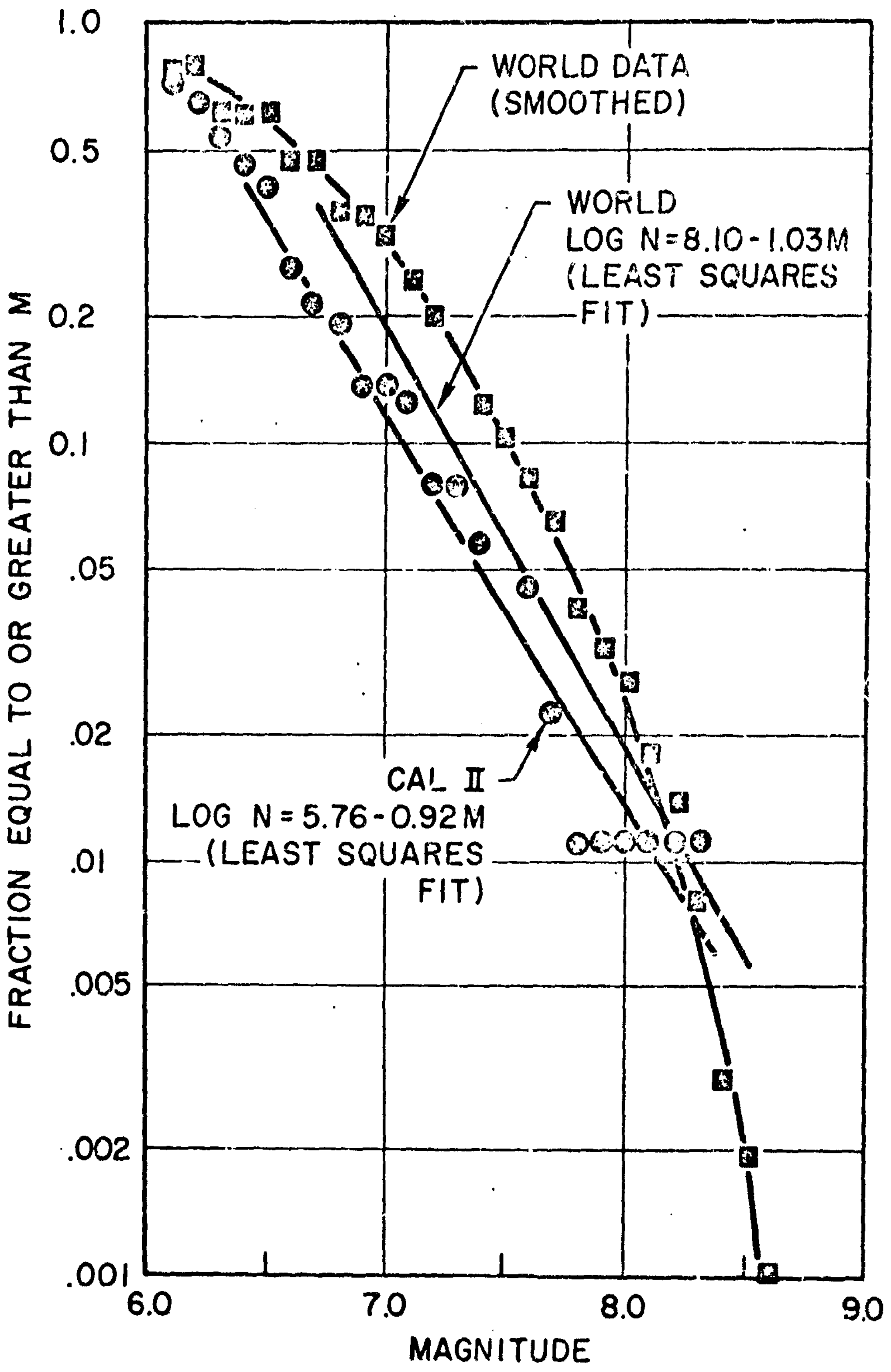

FIGURE 1

A similar continuum of frequency logarithmically inverse to severity can be shown in an analysis of motor vehicle accidents. In Figure 2 is shown the annual number of motor vehicle accidents in the State of California for the years 1968 and 1969 as a function of the number of vehicles involved in the accident. Because the vehicle population in California is very large (more than 9 million registered) and the accidents are roughly stochastically random, the frequency versus severity curve may be expected to approximate a Poisson probability law - similar to that shown in Figure 2.

The continuous spectrum of damaging events is also illustrated by theoretical studies of hypothetical nuclear power plant accidents. A recent analysis by Otway* for a typical pressurized water reactor 1000 MWe power plant has given the results shown in Figure 3. The similarity to the earthquake curves is apparent. Here the probability per year (or frequency) approximately varies inversely as the square of the fission product release per event. Figure 3 also shows that there is a characteristic probability curve for each type of accident chain. This would be expected, as major differences in initiating events produce largely different accident sequences.

The spectrum of relationships between accident frequency and their severity may be generalized by the three-dimensional sketch shown in Figure 4. The range of disability goes from minor inconvenience to death. At each point on this disability scale, is an associated curve of frequency versus the number of people involved. In this paper, I have chosen to discuss only the fatal end point. However, a complete study would integrate the effects of all accidents, minor to fatal, and with proper cost factors, determine the total weighted public risk and the social cost. Even for fatalities alone, the weighting factor of age is very significant —as shown in Figure 5. This type of comprehensive analysis should be undertaken for a

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*H.J. Otway, "The Application of Risk Allocation to Reactor Siting and Design." 1969. Ph.D. Thesis, UCLA. Los Alamos Scientific Laboratory, University of California, LA-4316.

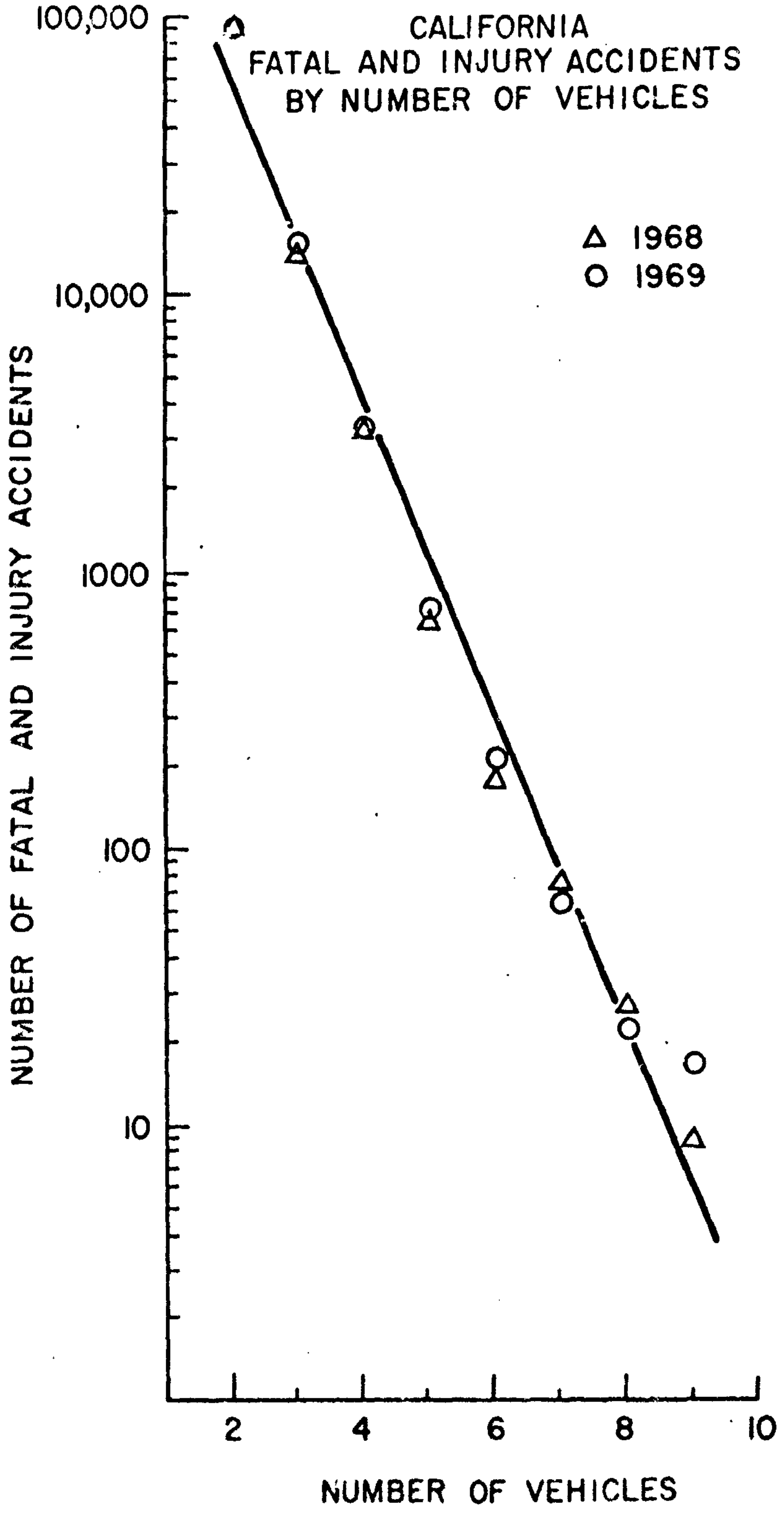

CALIFORNIA
FATAL AND INJURY ACCIDENTS
BY NUMBER OF VEHICLES
△ 1968
○ 1969
100,000
10,000
1000
100
10
NUMBER OF FATAL AND INJURY ACCIDENTS
2
4
6
8
10
NUMBER OF VEHICLES

FIGURE 2

FISSION PRODUCT RELEASE VS PROBABILITY

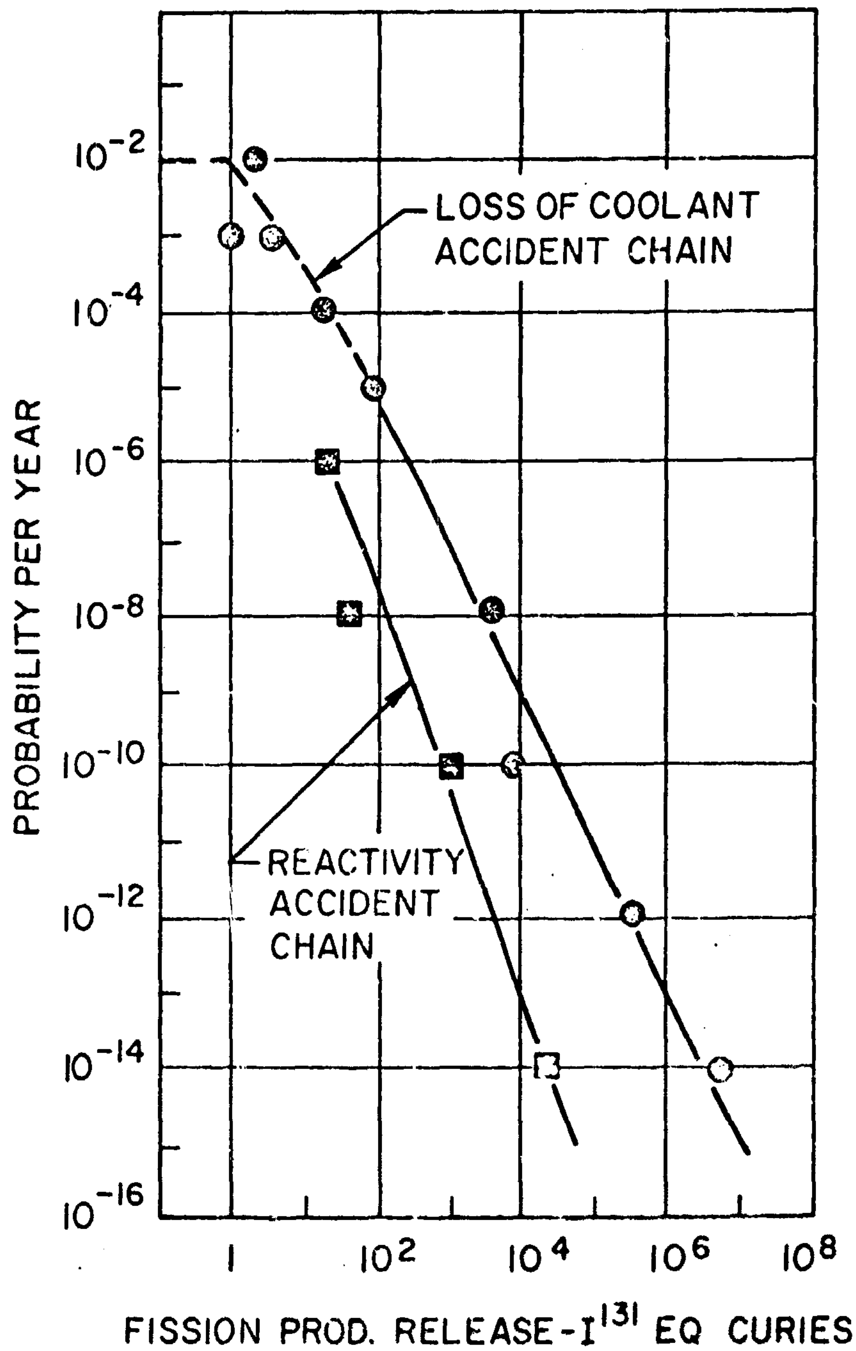


FIGURE 3

INSERT In addition to the probability curve for the magnitude of an accident, each individual size of accident produces a variety of public impacts ranging from minor disabilities to death. As one would expect, the bulk of data available for specific accident types, as for example, motor vehicle collisions, all indicate that the number of minor disabilities is very much greater than the fatalities. Although good data is generally lacking to properly quantify such distribution of effects, the same general characteristic appears to apply to most public exposures to hazards. For example, in Figure 3' the impact of sulfur dioxide air pollution on public health is shown in an approximate manner. This is a typical dosage relationship with a major influence of dose rate. Proper evaluation of public hazards should include estimates of those non-lethal disability effects.

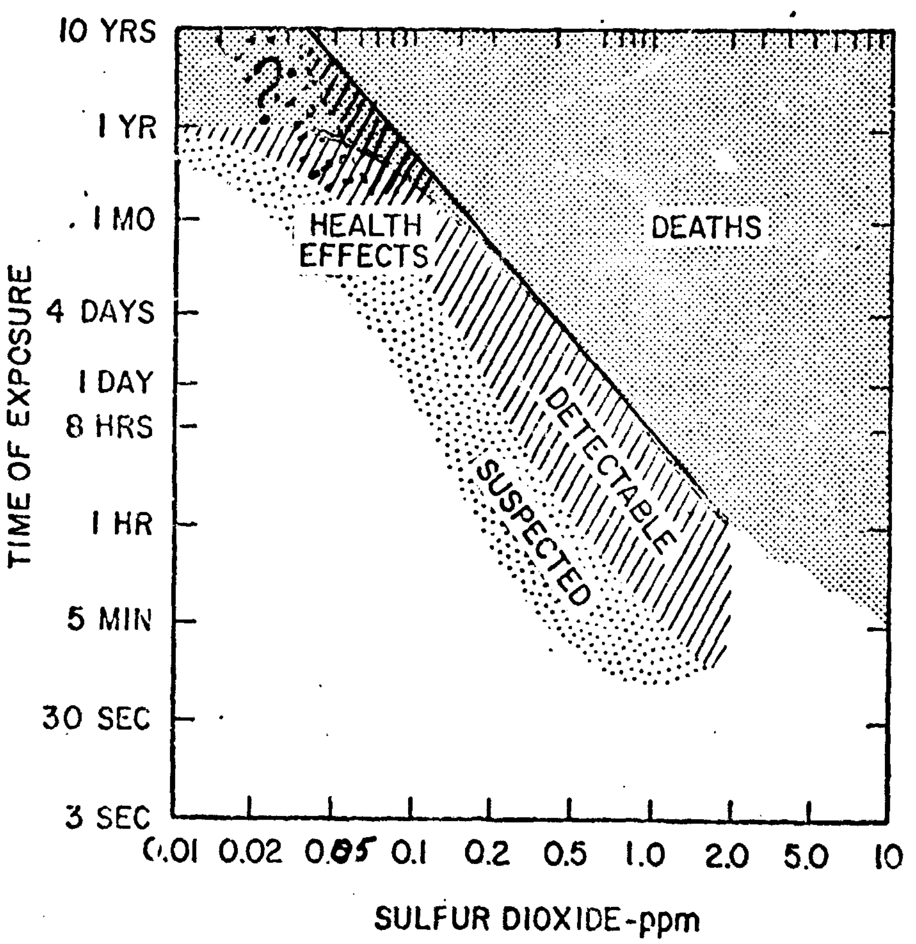


FIGURE 3'

ACCIDENT CHAIN PATTERN

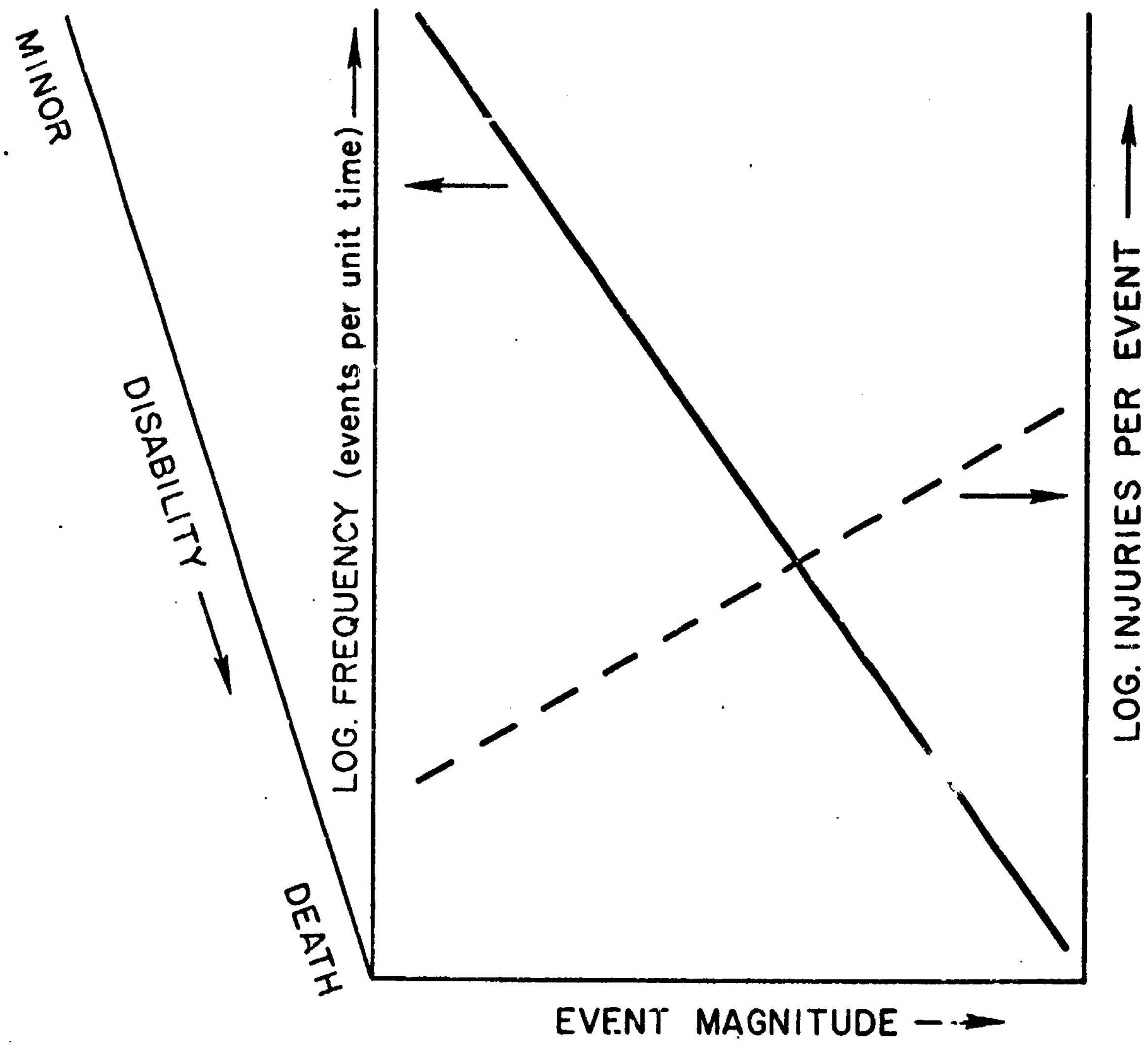
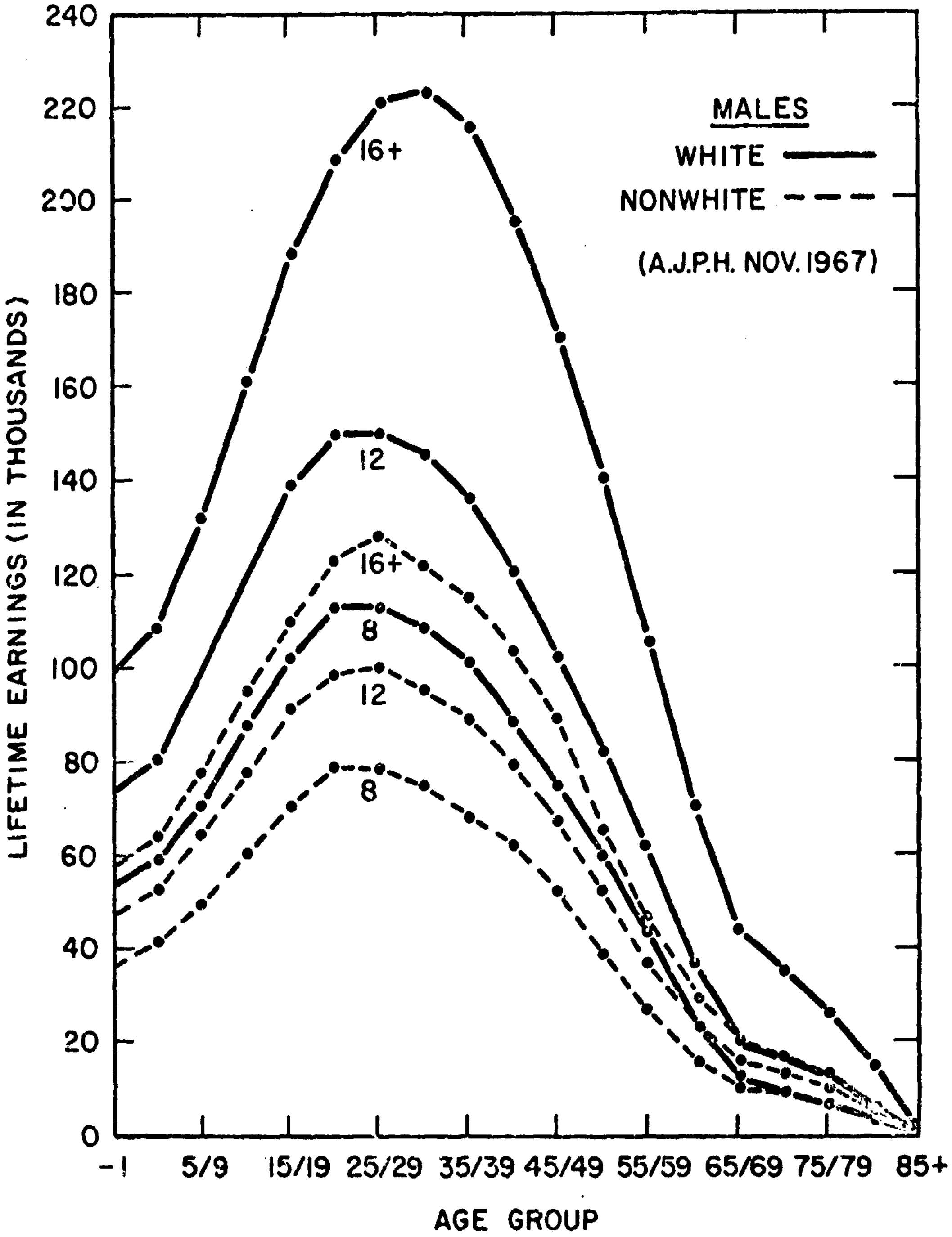


FIGURE 4



PRESENT VALUE OF LIFETIME EARNINGS OF MALES, BY YEARS OF SCHOOL COMPLETED, DISCOUNTED AT 4%, 1964

FIGURE 5

meaningful benefit-cost comparison for a specific technical system. This paper is not intended to be comprehensive, and reviews only the scope and magnitude of the basic methodology.

The nuclear power plant example mentioned, raises some fundamental questions about our societal approach to public risk. The dramatic aspect of the unfamiliar large catastrophe – but with exceedingly low probability – tends to draw both public attention and concern. Unlike the natural catastrophes – earthquakes, typhoons, floods, tidal waves, etc. – society has not learned to place such hypothetical man-made events in an acceptable comparative perspective, particularly when they are poorly understood by the public. If, in fact, the low release events are of more importance, the concern with imaginary large catastrophes may seriously distort both societal policy decisions and, as a result, engineering design emphasis.

In the particular case of nuclear power, it is unlikely that this issue will be resolved by practical experience. The probability of the large events plotted in Figure 3 are so low, that actuarial insight based on the statistics of real nuclear accidents will probably never exist. It is important to recognize the comparative scale of the extremely small probabilities involved in the nuclear accident chain shown in Figure 3. Let us use as a comparative measure natural disasters – floods, earthquakes, tornadoes, and storms. Averaged over the U.S., these cause five to ten deaths per million population per year. The probability of causing this same level of fatalities by the nuclear accident chain of Figure 3 is less than 10^{-6} per year – that is, once in a million years of operation of a nuclear power station.

It is, of course, very comforting that the public risk from nuclear power plant accidents is in fact so low. However, it does emphasize the importance of the analytic approach to risk assessment, and the development of a societal philosophy, perspective, and criteria for evaluating the benefit-risk relationships. How should we approach

the "once in a hundred years" earthquake, or the somewhat equivalent "once in a million years" nuclear accident? Do we passively accept the first and not the second? Both risks can be reduced by preventive engineering design and added costs. What is the value to our society in allocating resources now for reducing such time-remote risks? What is a "negligible" risk - that is, one which we consciously decide to neglect? When do we philosophically shift the burden of responsibility from an "act of man" to an "act of God?"

It is to these questions that the remainder of this discussion will be addressed - with the objective of suggesting a methodology for a rough quantitative approach to their answers.

Quantitative Correlations

With this definition of the problem, and the associated caveats, we are in a position to discuss the quantitative correlations. For the sake of simplicity, the measure of the risk to the individual has been restricted to the fatalities (deaths) associated with each type of activity. Although it clearly would be useful to include all injuries (which are 100 to 1000 times as numerous as deaths), the difficulty in obtaining data and the unequal penalties of varying disabilities would introduce inconvenient complexity for this study. So the risk measure used here is the statistical probability of fatalities per hour of exposure of the individual to the activity considered.

The hour-of-exposure unit was chosen because it was deemed more closely related to the individual's intuitive process in choosing an activity than a year of exposure would be, and gave substantially similar results. Another possible alternative, the risk per activity, involved a comparison of too many dissimilar units of measure; thus, in comparing the risk for various modes of transportation, one could use risk per hour, per mile, or per trip. As this study

was directed toward exploring a methodology for determining social acceptance of risk, rather than the safest mode of transportation for a particular trip, the simplest common unit – that of risk per exposure hour – was chosen.

The social benefit derived from each activity was converted into a dollar equivalent, as a measure of integrated value to the individual. This is perhaps the most uncertain aspect of the correlations because it reduced the "quality-of-life" benefits of an activity to an overly simplistic measure. Nevertheless, the correlations seemed useful, and no better measure was available. In the case of the "voluntary" activities, the amount of money spent on the activity by the average involved individual was assumed proportional to its benefit to him. In the case of the "involuntary" activities, the contribution of the activity to the individual's annual income (or the equivalent) was assumed proportional to its benefit. This assumption of roughly constant relationship between benefits and monies, for each class of activities, is clearly an approximation. However, because we are dealing in orders of magnitude, the distortions likely to be introduced by this approximation are relatively small.

In the case of transportation modes, the benefits were equated with the sum of the monetary cost to the passenger and the value of the time saved by that particular mode relative to a slower, competitive mode. Thus, airplanes were compared with automobiles, and automobiles were compared with public transportation or walking. Benefits of public transportation were equated with their cost. In all cases, the benefits were assessed on an annual dollar basis because this seemed to be most relevant to the individual's intuitive process. For example, most luxury sports require an investment and upkeep only partially dependent upon usage. The associated risks, of course, exist only during the hours of exposure.

Probably the use of electricity provides the best example of the analysis of an "involuntary" activity. In this case the fatalities

include those arising from electrocution, electrically caused fires, the operation of power plants, and the mining of the required fossil fuel. The benefits were estimated from a United Nations study of the relationship between energy consumption and national income. The contributions of the home use of electric power to our "quality of life" – more subtle than the contributions of electricity in industry – are omitted. The availability of refrigeration has certainly improved our national health and the quality of dining. The electric light has certainly provided great flexibility in patterns of living, and television is a positive element. Perhaps, however, the gross-income measure used in the study is sufficient for present purposes.

Information on acceptance of "voluntary" risk by individuals as a function of income benefits is not easily available, although we know that such a relationship must exist. Of particular interest, therefore, is the special case of miners exposed to high occupational risks. In Figure 6, the accident rate and the severity rate of mining injuries are plotted against the hourly wage. The acceptance of individual risk is an exponential function of the wage, and can be roughly approximated by a third-power relationship in this range.

Risk Comparisons

As a reference level for comparing risks, it seemed appropriate to take the risk of death due to disease. This is shown in Figure 7 for the U.S. population, both for disease and accidents. The average accident fraction is about one-tenth of the disease average, and its presence is not significant. However, if one considers the younger population (10-30), the disease level is a magnitude less than the average, and the accident level is actually larger. The reverse is obviously true for the oldest group. In a more complete study, the varying value of human life with age – from a societal viewpoint – would require special emphasis on the age group from 20-50 years, whose social value may be several times that of the younger and older. Aside from the complex humanistic judgments intrinsic to

MINING ACCIDENT RATES VS. INCENTIVE

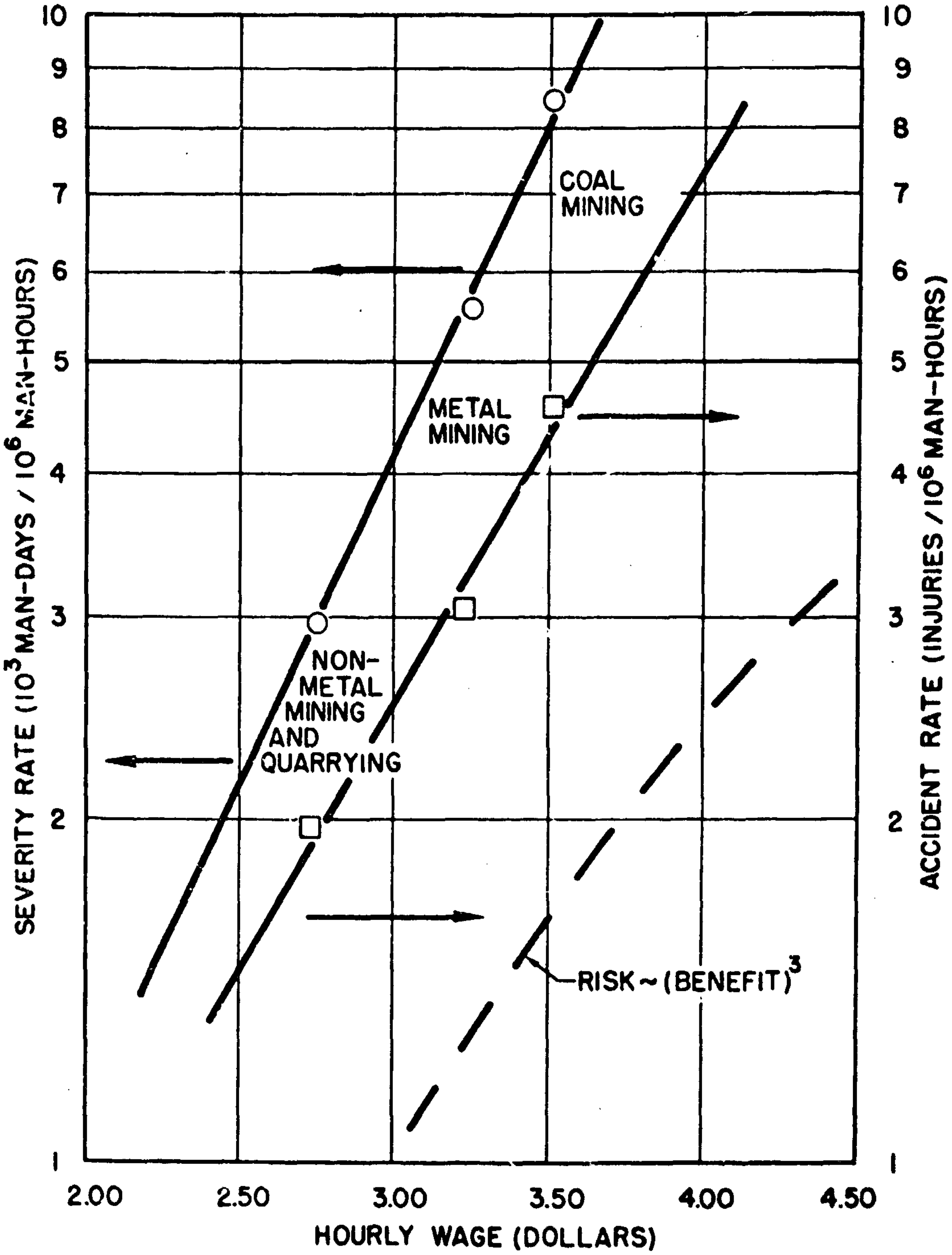


FIGURE 6

RISK VS. AGE GROUP
FOR
ACCIDENTS AND DISEASE

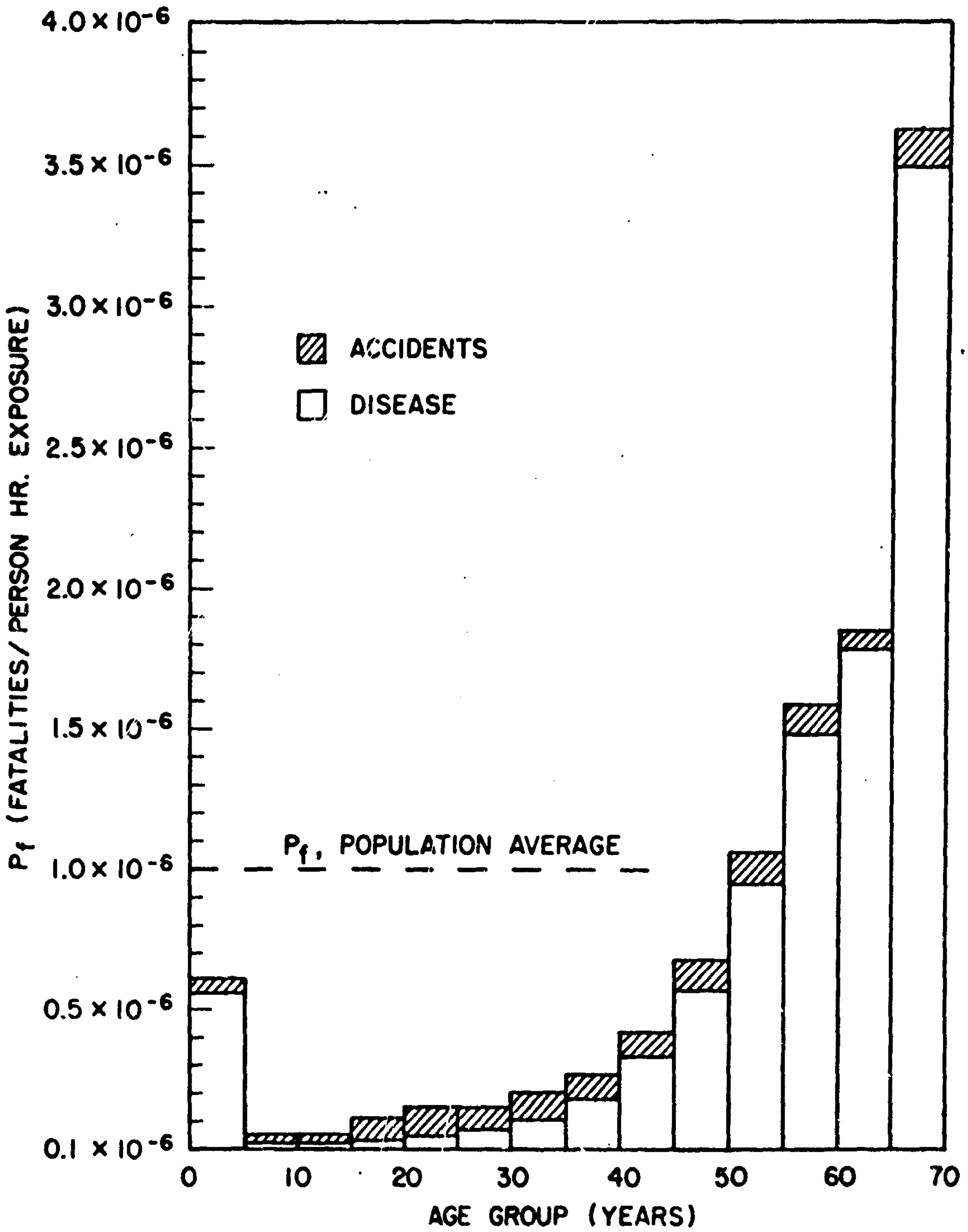


FIGURE 7

this approach, the present study is too general to justify this refinement.

The results for the societal activities studied, both "voluntary" and "involuntary," are assembled in Figure 8. Also shown in Figure 8 is the third-power relationship between risk and benefit characteristic of Figure 6. The average risk of death from disease is indicated for comparison.

Several major features of the benefit-risk relations are apparent, the most obvious being the difference by several orders of magnitude in society's willingness to accept "voluntary" and "involuntary" risk. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis. The risk of death in most sporting activities is surprisingly close to the risk of death from disease – almost as though, in sports, the individual's subconscious computer adjusted his courage and made him take risks associated with a fatality level equaling but not exceeding the statistical mortality due to involuntary exposure to disease. Perhaps this defines the demarcation between boldness and foolhardiness.

The simple ratio of benefit to risk is conventionally used as an index of societal acceptability. This is not consistent with the hypothesized logarithmic relationship of Figure 8. As one moves toward higher benefits along either suggested band, the benefit/risk ratio drops rapidly due to the $R \sim B^3$ relation. Thus, the simple ratio is apt to be quite misleading in considering social value and acceptability of an activity.

The risks associated with general aviation, commercial aviation, and travel by motor vehicle deserve special comment. The latter

RISK VS. BENEFIT
VOLUNTARY AND INVOLUNTARY EXPOSURE

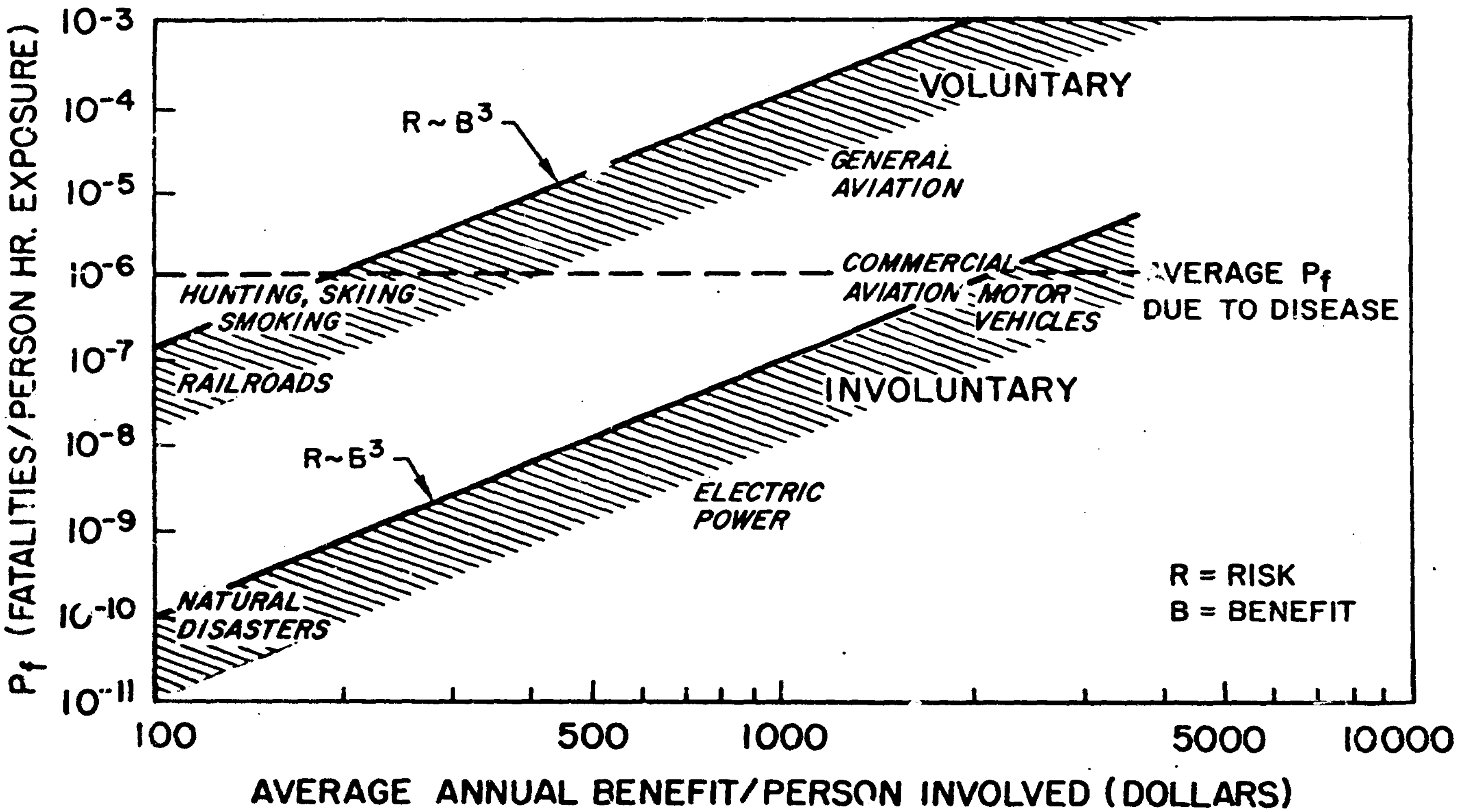


FIGURE 8

originated as a "voluntary" sport, but in the past half-century the motor vehicle has become an essential utility. General aviation is still a highly voluntary activity. Commercial aviation is partly voluntary and partly essential and, additionally, is subject to government administration as a transportation utility.

Travel by motor vehicle has now reached a benefit-risk balance, as shown in Figure 9. It is interesting to note that the present risk level is only slightly below the basic level of risk from disease. In view of the high percentage of the population involved, this probably represents a true societal judgment on the acceptability of risk in relation to benefit. It also appears from Figure 9 that future reductions in the risk level will be slow in coming, even if the historical trend of improvement can be maintained.

Commercial aviation has barely approached a risk level comparable to that set by disease. The trend is similar to that for motor vehicles, as shown in Figure 10. However, the percentage of the population participating is now only 1/20 that for motor vehicles. Increased public participation in commercial aviation will undoubtedly increase the pressure to reduce the risk, because, for the general population, the benefits are much less than those associated with motor vehicles. Commercial aviation has not yet reached the point of optimum benefit-risk trade-off.

For general aviation the trends are similar, as shown in Figure 11. Here the risk levels are so high (20 times the risk from disease) that this activity must properly be considered to be in the category of adventuresome sport. However, the risk is decreasing so rapidly that eventually the risk for general aviation may be little higher than that for commercial aviation. Since the percentage of the population involved is very small, it appears that the present average risk levels are acceptable to only a limited group.

RISK AND PARTICIPATION TRENDS
FOR
MOTOR VEHICLES

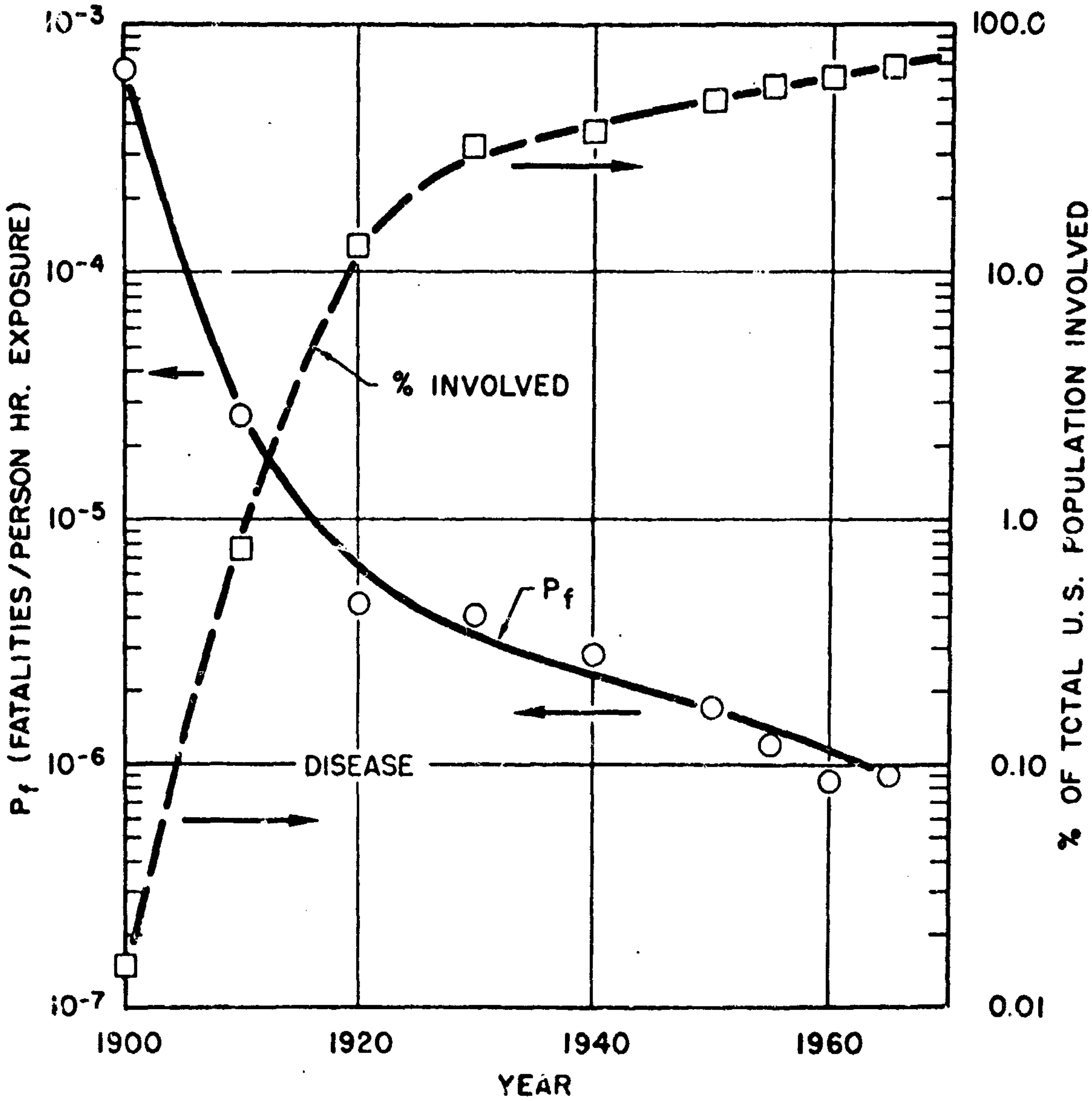
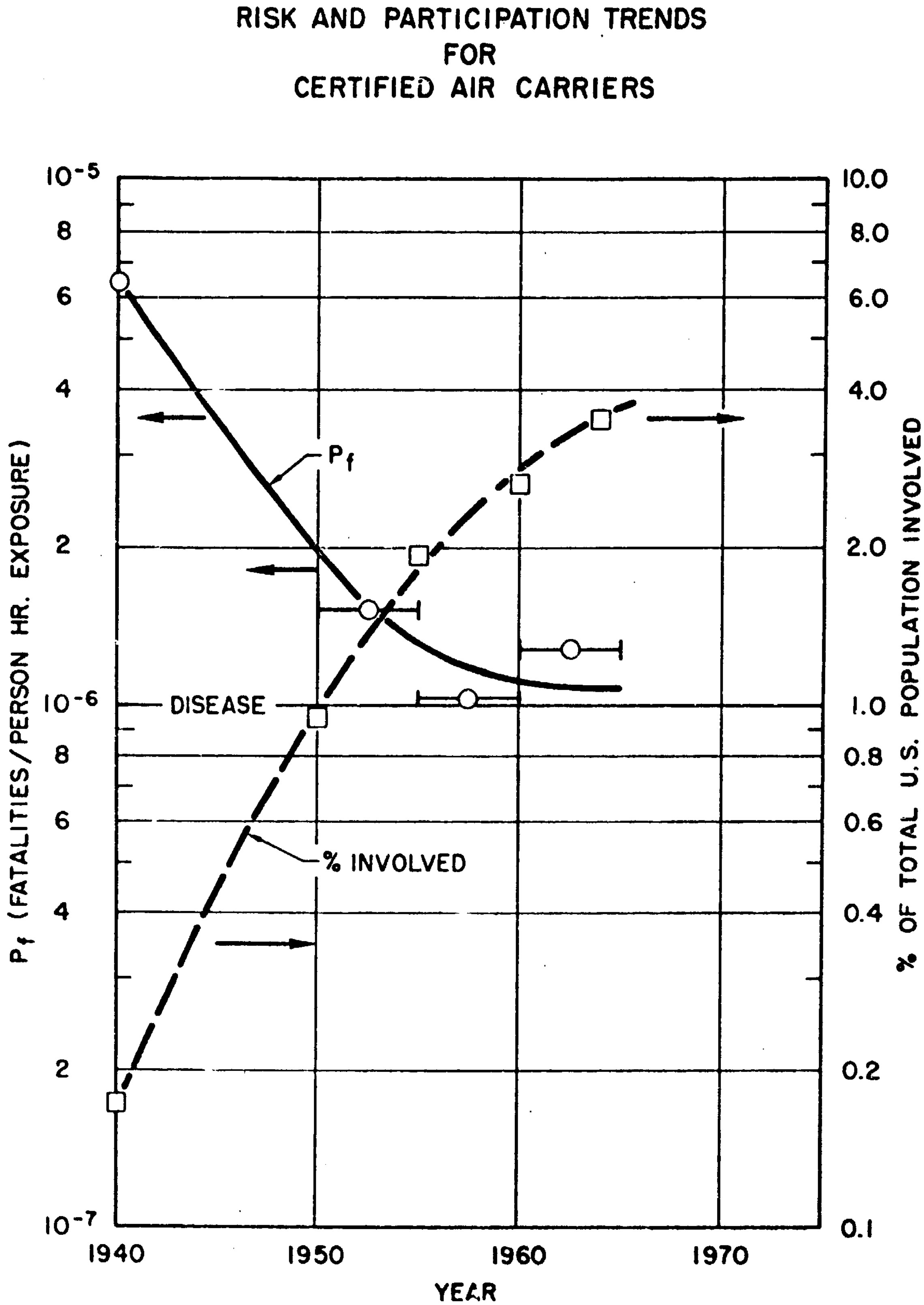


FIGURE 9



RISK AND PARTICIPATION TRENDS
FOR
CERTIFIED AIR CARRIERS
10^{-5}
8
6
4
2
10^{-6}
8
6
4
2
10^{-7}
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
P_f
DISEASE
% INVOLVED
P_f (FATALITIES/PERSON HR. EXPOSURE)
% OF TOTAL U.S. POPULATION INVOLVED
1940
1950
1960
1970
YEAR

FIGURE 10

RISK AND PARTICIPATION TRENDS
FOR
GENERAL AVIATION

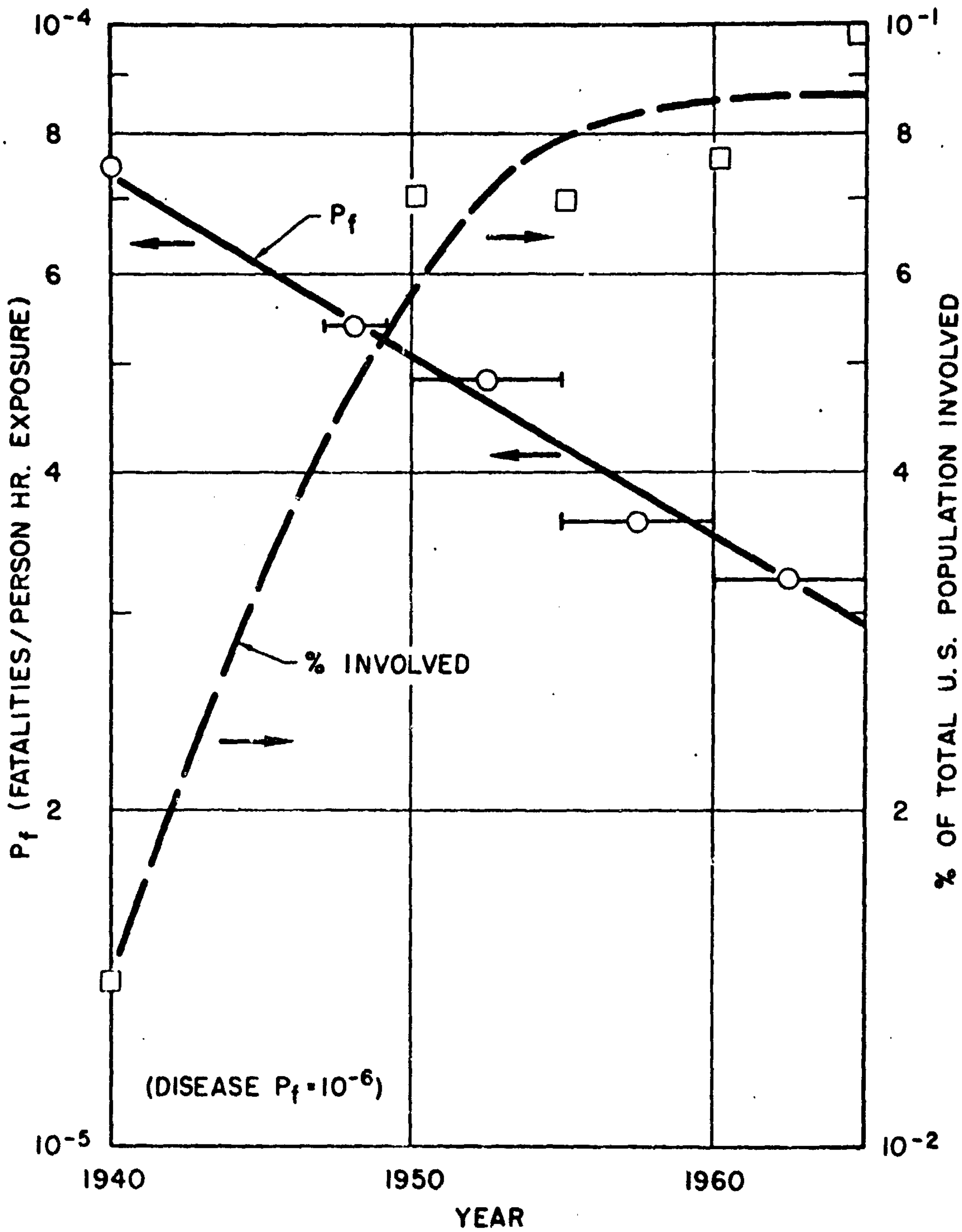


FIGURE 11

Farm tractor accidents do not conform to this general trend that increased population participation results in decreased individual risk.* Figure 12 shows the growth in the mechanization of agriculture in the past half century, but not much change in the individual risk. This situation might indicate that the risk arises from the mode of use of the tractor, rather than inadequate machine design. In view of the highly variable terrain, and types of operation in which tractors are used, it is likely that the P_f level is established by the individual operator as acceptable to him.

A group risk (risk x population exposed) study has been made for nonmilitary vessels,+ shown in Figure 13. The span of eight years (1960-68) is too short to show long term trends. However, the difference in risk between recreational boating and commercial vessels again shows the 1000 or more spread between voluntary and involuntary exposures accepted by the participants. The traditional risks of the professional seamen and fishermen appear modest as compared to that of the daily commuter driving to work.

Public Awareness

Finally, I attempted to relate these risk data to a crude measure of public awareness of the associated social benefits (see Figure 14). The "benefit awareness" was arbitrarily defined as the product of the relative level of advertising, the square of the percentage of population involved in the activity, and the relative usefulness (or importance) of the activity to the individual. Perhaps these assumptions are too crude, but Figure 14 does support the reasonable position that advertising the benefits of an activity increases public acceptance of a greater level of risk. This, of course, could subtly produce a fictitious benefit-risk ratio – as may be the case for smoking.

*Private communication: James E. Giesen, Product Safety Department, Deere & Company, December 3, 1969.

+Private communication: R. J. Bosnak, Commander, U.S. Coast Guard, December 24, 1969.

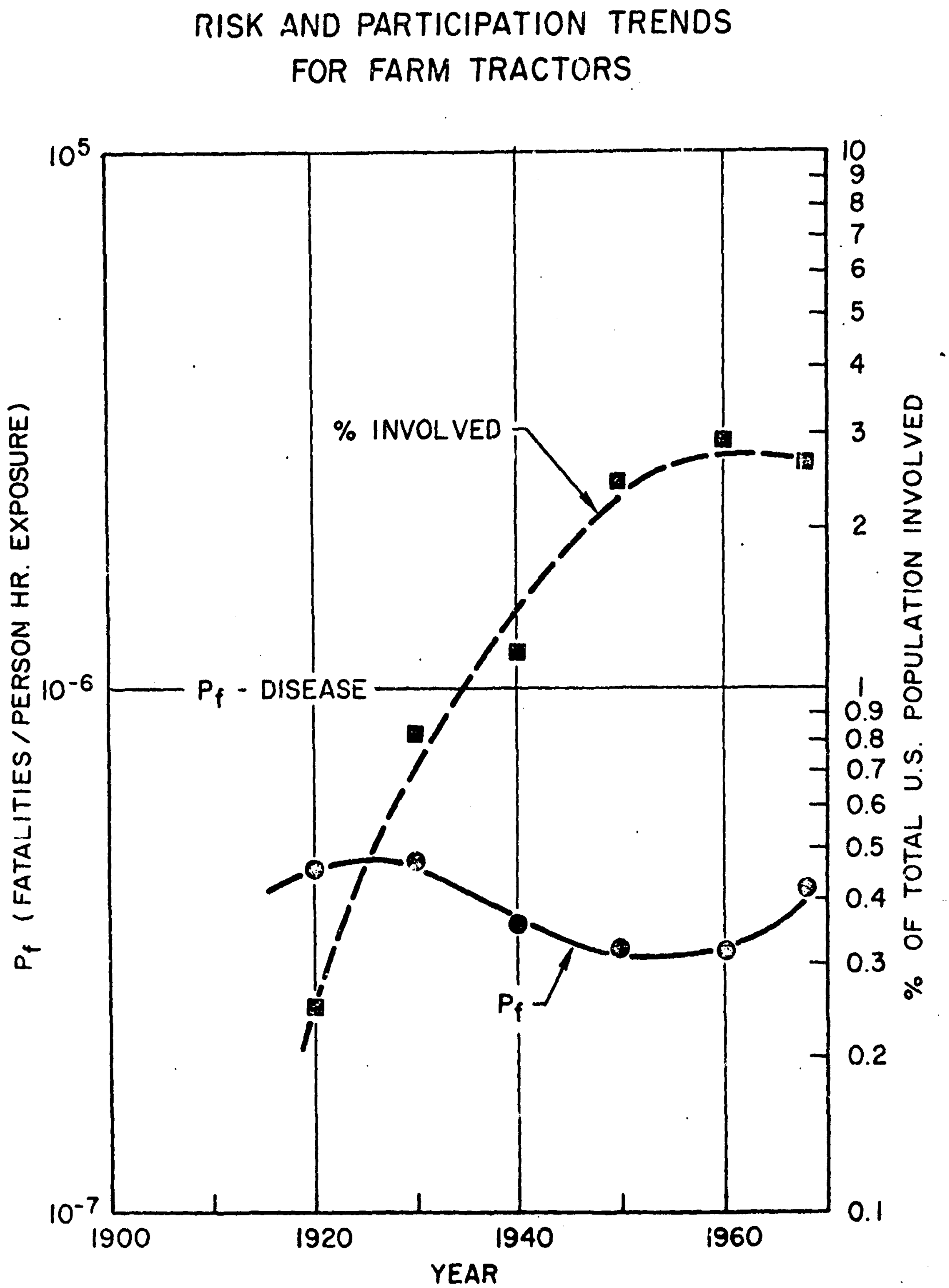

RISK AND PARTICIPATION TRENDS
FOR FARM TRACTORS
10^{5}
10^{-6}
10^{-7}
P_f (FATALITIES / PERSON HR. EXPOSURE)
% INVOLVED
P_f - DISEASE
P_f
1900
1920
1940
1960
YEAR
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
% OF TOTAL U.S. POPULATION INVOLVED

FIGURE 12

GROUP RISK VS YEAR

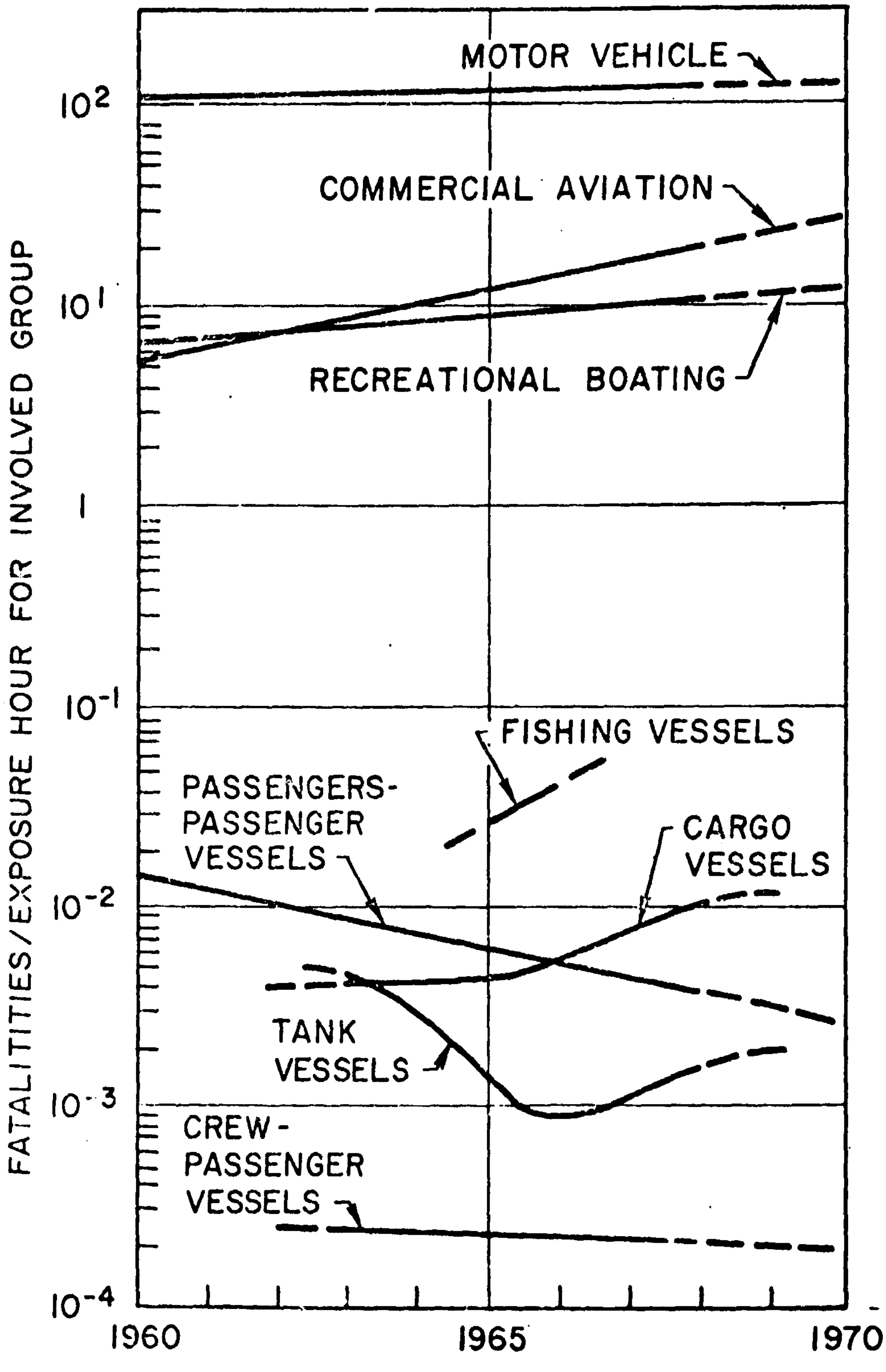


FIGURE 13

ACCEPTED RISK VS BENEFIT AWARENESS

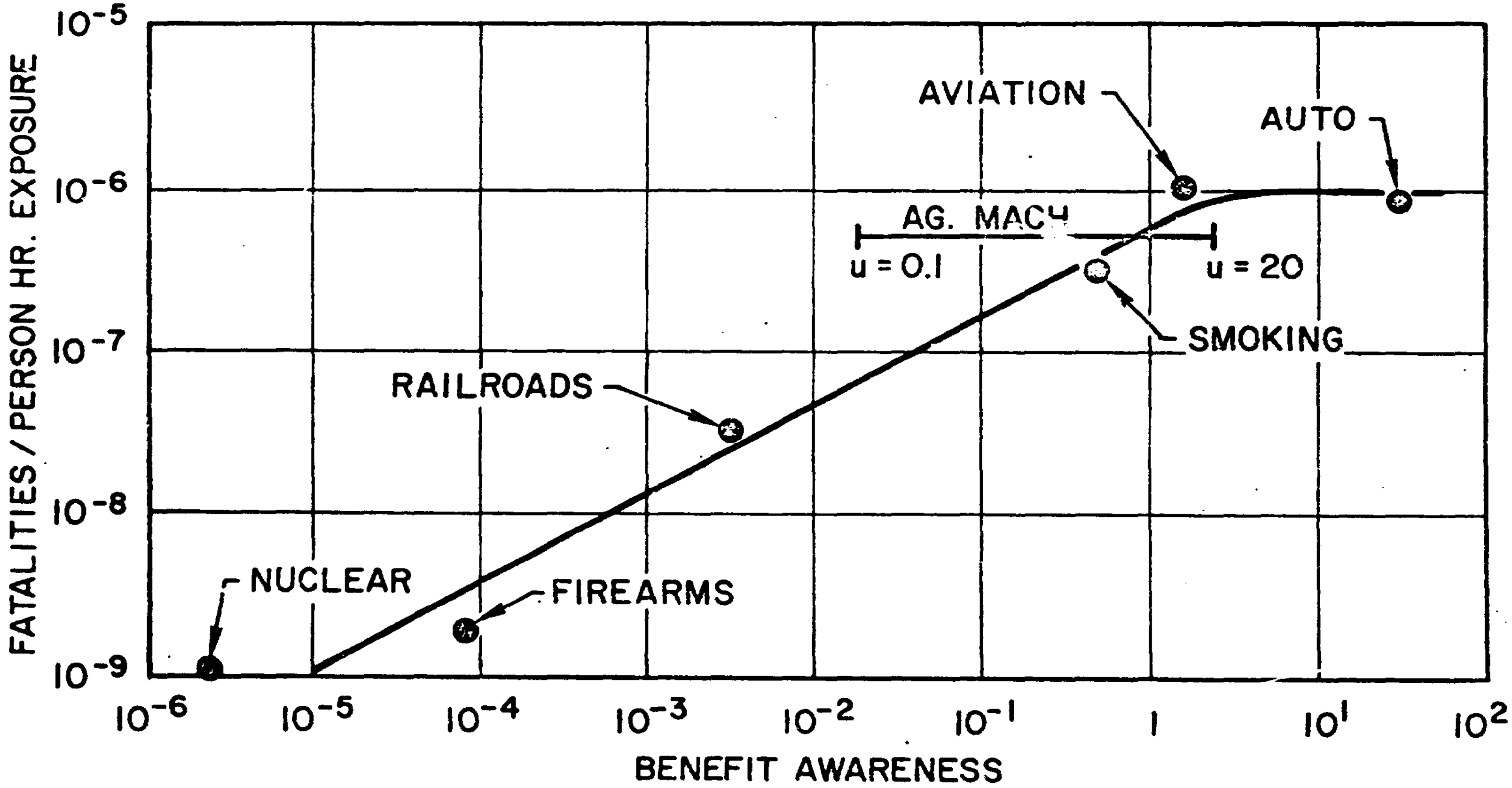


FIGURE 14

This study is only an exploratory application of the methodology of historical analysis for revealing social preferences, values, and benefit-cost relationships. On the specific illustrative question: "How safe is safe enough?" it does reveal several interesting points. These may suggest an initial basis for judicious national decisions on involuntary risk associated with our socio-technical systems. The premises for such a societal policy may be summarized as follows.

1. Rate of death from disease is an upper guide in determining the acceptability of risk – somewhat less than 1 in 100 years.
2. Natural disasters ("acts-of-God") tend to set a base guide for risk – somewhat more than 1 in a million years – similar to the intrinsic "noise" level of physical systems. Man-made risks at this level can be considered almost negligible, and can certainly be neglected if they are several magnitudes less.
3. As would be expected, societal acceptance of risk increases with the benefits to be derived from an activity. The relationship appears to be nonlinear, with this study suggesting that the acceptable level of risk is an exponential function of the benefits (real and imaginary).
4. The public appears willing to accept "voluntary" risks roughly 1000 times greater than "involuntary" exposure risks.
5. The quantitative risk analysis of a specific socio-technical system – such as atomic power – should take into account the continuous spectrum of accident frequency versus severity, both of the system under study and of comparative systems. The present study has not entered into the "fine-structure" of the problem. A more definitive and intensive analysis is needed for application to specific national policy guidelines.

Conclusion

Societal policy for the acceptability of public risks associated with socio-technical systems should be determined by the trade-off between social benefits and personal risk. As suggested above, the upper bound of such risk is the disease level and the lower bound is several magnitudes below the natural disaster level, as illustrated in Figure 15. This provides a risk trade-off range of one million for

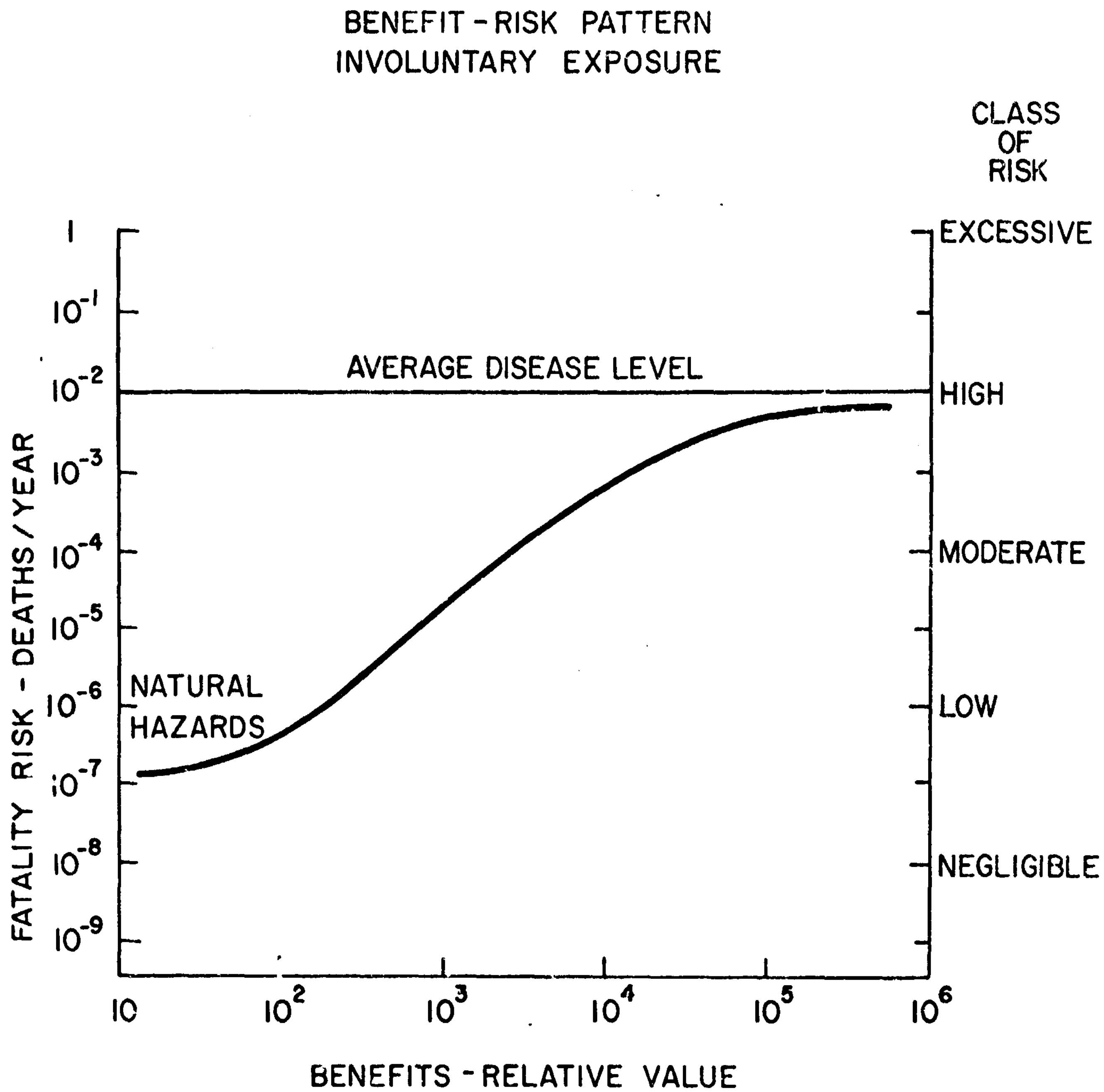

BENEFIT - RISK PATTERN
INVOLUNTARY EXPOSURE
CLASS OF RISK
EXCESSIVE
HIGH
MODERATE
LOW
NEGLIGIBLE
AVERAGE DISEASE LEVEL
NATURAL HAZARDS
FATALITY RISK - DEATHS / YEAR
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10
10^2
10^3
10^4
10^5
10^6
BENEFITS - RELATIVE VALUE

FIGURE 15

social policy determination — from an individual risk of one fatal accident in a hundred years, to one in a hundred million years.

It is evident that we need much more study of the methodology for evaluating social benefits and costs. The fatality measure of public risk is perhaps more advanced than most because of decades of data collection. Nevertheless, even the use of crude measures of both benefit and costs would assist in the development of the insight needed for national policy purposes. We should not be discouraged by the complexity of this problem — the answers are too important, if we want a rational society.

TECHNOLOGY AND SAFETY - A QUALITATIVE VIEW

by

Roy Reider
Safety Director

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

ABSTRACT

A retrospective analysis of the contribution of new technology to improving the safety of society. An examination of the risk imposed by a new technology and the control of that risk by increased knowledge, by legislation, by self-imposed standards and by social pressure from an aware consumer.

TECHNOLOGY AND SAFETY - A QUALITATIVE VIEW

Roy Reider

A thoughtful look at technology and society will show, I believe, that new technologies tend to make living safer, that a new technology replaces a more hazardous one. It may be equally true that a new technology introduces a new risk; nevertheless, that new risk tends to lessen with maturity of the technology. In more modern times, as recently as this generation, an aware society is more critically examining the technical contributions for their safety considerations.

SEA TRANSPORT

The greatest practical navigators in the history of man were the adventurous sailors of the outrigger canoes of the Pacific Islands. As these tiny islands and atolls were hundreds of miles apart extraordinary strength, skill and daring were required to move between islands and atolls. Despite the unique abilities of these intrepid Micronesians the continuing loss of men from hazardous voyages was one of the forces that helped keep population in balance with the tiny land masses.

In the past generation outrigger voyages have essentially ceased. With the availability of power boats there is no interest in the more primitive transport.

I offer this simple example of a theorem that a new technology tends to reduce the hazards to society.

In this example we see that transportation of man with improved navigational aids and more reliable transport vehicles has been a continuing technical contribution to man's safe mobility.

ANESTHESIA

Shortly before the middle of the 19th century mankind was treated to a demonstration of triumph over pain when anesthesia was used in a publicized surgical procedure. Before this time there had been some use of anesthetic gases and vapors but only in an uneven fashion and then often in fun and games. Laughing gas demonstrations and ether parties were actually held for public view and participation and sometimes tickets were sold. Both opium and alcohol had been used historically but they were not reliable anesthetic substances.

In 1846 ether was used on a patient undergoing neck surgery in Boston. Immediately after this ether was used in a leg amputation in Great Britain. Later, chloroform was given to Queen Victoria in childbirth.

> Original Ether Day, Boston, October 16, 1846. Dr. Morton (left) holds inhaler while Dr. J. C. Warren excises tumor on jaw of patient. Morton was a dentist and could not perform surgery. First amputation under ether performed by Robert Liston in London, December 21, 1846. This amputation was timed in 28 seconds as speed was so essential in pre-anesthesia days.

The tremendous gain in safety contributed by new technology was immediate and obvious. The shock to patients from the pain of the procedure was

reduced; the physician could employ more deliberate skill with a patient submerged in coma. Successfully carried out were procedures that heretofore could hardly be attempted.

Howe , new technology, though it moderate or even eliminate an old risk, does introduce a new risk. So did anesthesia. There were a variety of problems: liver damage from the toxicity of the vapor, hypoxia from a shortage of oxygen and a depression of the activity of the respiratory system.

After a half century of use of anesthesia-air mixtures oxygen was introduced. This solved many of the physiological safety problems and introduced new physical ones of increased fire and explosion risk. The enrichment by oxygen not only broadened the explosive range of the combustible anesthetic vapor but also significantly reduced the amount of energy necessary to ignite the mixture.

After another 25 years hydrocarbon gases such as ethylene and cyclopropane were introduced. These gases permitted better control of the depth and time of patient submergence but with very little energy an accidental ignition could occur.

Control measures were introduced to eliminate ignition sources. Voluntary safety standards were developed beginning on a national basis about 30 years ago.

In recent years the over-all death rate directly attributable to anesthesia has been given as about one in 1000 cases; the mortality rate from anesthesia explosions is estimated at less than one in 1,000,000 anesthesias. The emotional factors involved in an anesthetic explosion, however, make it feared out of proportion to its incidence. Enormous, almost continuous,

gains in anesthetic technique gave increasing safety. Today, new halogenated non-flammable inhalation anesthetics and new intravenous agents, also non-flammable, offer promise to eliminate any need for heroic control of ignition sources.

These safety gains have not required much social legislation other than licensure of practitioners. There has always of course been the implied varied penalties of accidents, including negotiated or court-ordered costs where negligence might be demonstrated.

BOILERS

Well before the middle of the 19th century steam boilers were blowing up with astonishing regularity, causing multiple deaths particularly when they occurred on steamboats. From 1825 to 1830 there had been forty-two explosions killing about 273 persons.

In the period 1841-1848 there were some seventy marine explosions that killed about 625 persons. The toll in 1850 was 277 dead from explosions and in 1851 it rose to 407.

There had been some boiler legislation in 1838 but it was ineffective. It specified inspection of boilers but did not qualify the inspectors; it imposed penalties when negligence could be demonstrated but negligence was infrequently found and even more rarely were penalties imposed. Often if an inspection were too strict in one jurisdiction boats would seek out another jurisdiction where the boiler inspection would be a little more casual.

In 1852 more stringent and effective boiler legislation was passed. In the decade that followed accidents dropped significantly. However only steamboats were affected. An editor of a technical journal wrote at this time, "Since the passage of the law steamboat explosions on the Atlantic have become almost unknown, and have greatly decreased in the west. With competent inspectors, this law is invaluable, and we hope to hail the day when a similar act is passed in every legislature, touching locomotives and stationary boilers."

The debate for the 1852 legislation had powerful arguments on each side: A major argument against passage was the threat to private property rights, in the following words, for example:

> "It is this - how far the Federal Government...shall be permitted to interfere with the rights of personal property - or the private business of any citizen...under the influence of recent calamities, too much sensibility is displayed on this subject... I hold it to be my imperative duty not to permit my feelings of humanity and kindness to interfere with the protection which I am bound, as a Senator of the United States, to throw around the liberty of the citizen, and the investment of his property, or the management of his own business... what will be left of human liberty if we progress on this course much further? What will be, by and by, the difference between citizens of this far-famed Republic and the serfs of Russia? Can a man's property be said to be his own, when you take it out of his own control and put it into the hands of another, though he may be a Federal officer?"

But a telling argument for the bill used these words:

"'I consider that the only question involved in the bill is this: Whether we shall permit a legalized, unquestioned, and peculiar class in the community to go on committing murder at will, or whether we shall make such enactments as will compel them to pay some attention to the value of life.' It was, then, a question of the sanctity of private property rights as against the duty of government to act in the public weal."

By 1854 the Journal of the Franklin Institute was courageous enough to say:

"Whenever we have an account of a boiler explosion, we hear the cry for a week or so for new laws, and more stringent provisions, careful inspection, &c., &c., and the General, State, and Municipal Governments are in turn solicited for their interference, and abused for the negligence, until the epidemic excitement has run its course in a few days, and all the clamor subsides, to be re-awakened by a new catastrophe."

In time through the agency of a professional society, the American Society of Mechanical Engineers, uniform boiler codes were promulgated and adopted by states and municipalities.

Thus, the reaction of the informed public, expressed by Congress, to boiler explosions caused the initiation of positive regulation of private enterprise through a governmental agency. The solution of the problem of bursting boilers was an important step toward the inauguration of the regulatory and

investigative agencies in the federal government. It took almost three generations to reach an acceptable level of safety. Regulation, as understood in modern times, is not an unacceptable way of life to the mercantile society. Even in the absence of regulation originating from the authority of the state many manufacturers and suppliers of dangerous commodities will self-impose restraints in the interest of public safety. Such restraint of course may also be of self-interest to avoid restrictive regulation by the state or simply to stay in business through the acceptance of a dangerous commodity by society because of a good safety record.

LIGHTING LEVELS

In looking at safety changes over a span of two generations one must examine not only technical gains but really the enormous social changes that take place. These social requirements for comfort and enjoyment perhaps influence gains in safety and health as much as technological improvements.

Lighting level standards (in footcandles) have had the following changes over a 50-year period:

	1916	1966
Stairways	0.75	30
Toilets, change rooms	1.00	30
Foundries	2.00	50
Rough work	2.00	40
Drafting	10.00	200
Fine work, precision work	4.00	100-1000
Office work	5.00	100
General storage	0.25	20

HURRICANE CAMILLE

I have been told by a meteorologist, one with a particular knowledge of large scale risk, that the 1969 hurricane Camille which struck the Gulf Coast was the most severe such storm to hit land in this century. Had Camille struck the same place 70 years ago the loss of life could reasonably be estimated to have been ten-fold greater. Early warnings, saturated public communication, good transport and good roads permitted preparations or escape so that loss of life was minimized. On the other hand, in underdeveloped areas forces of nature are extraordinarily devastating such as earth quakes in Peru or storms and floods in Pakistan.

PERMISSIBLE WHOLE BODY DOSES for OCCUPATIONAL EXPOSURES TO IONIZING RADIATION

A second theorem on technology and safety is that when a new technology introduces a risk that new risk tends to be reduced as the technology becomes widespread. Sometimes, as we will see in later examples, the technology must actually prove its safety, after initial introduction and misadventure, before it can be reestablished.

Less commonly, a technology may have to demonstrate its safety before initial acceptance. Nuclear power reactors typifies this class. An extraordinary paradox must be observed here: that is, freedom from accidents does not necessarily demonstrate a sufficient degree of safety. We will discuss this in more detail later.

This present example deals with permissible occupational exposures to ionizing radiation. During the early years of this century the dangers of radiation were recognized. But only qualitative standards were used; sort of "if the individual showed reddening of the skin, he has received too much."

In the 1920's the first limits were set by a national body which would permit about 100 rem per year. In 1934 this limit was reduced a third by an international body and reduced by two-thirds by a United States regulation. In 1950 the international standard permissive dose was down to 15 rem per year. Before the decade was over this was further reduced two-thirds and is today at 5 rem per year. Even with this relatively low permissible limit the number of exposed workers who approach the allowed level is only a few percent. Current design standards are setting as a practical goal levels only one-fifth of the permissible dose; this predicts a future allowable standard of one rem per year. This dramatic change in safety level was accomplished by regulation, by direction, by state-of-the-art improvements, and by realization that things ought to be and could be done more safely.

CRYOGENIC FLUIDS

In October 1944 in Cleveland, Ohio a fire and explosion occurred in a plant designed for the liquefaction, storage and regasifying of natural gas (methane). This was then the only plant of its kind. Large quantities of gas were needed for periods of peak demand - namely, the winter heating season. Formerly the site

of a water gas plant (which may have been a sparsely settled area when it was built 50 or more years before), it had been a liquefied gas storage location for three years. Private dwellings were as close as 100 feet from the fuel; the main line of a major railroad, and a foundry were also only short distances away.

A structural collapse of the vertical cylinder tank initiated the accident in which 130 lives were lost and 80 dwellings destroyed. The significant lesson learned from this misadventure was that, pending the ability to demonstrate reliability of materials and methods, sites should be selected with regard to reasonably safe locations to surroundings, particularly populated areas. Beginning 15 years after this incident liquefied methane technology renewed its activity and has met with success and acceptance since.

This accident involved 3,000,000 gallons of liquefied methane. In recent months I have been consulted on similar installations planned for urban areas which will have 50,000,000 gallons of fuel.

Ships now sailing between international ports have loads in the range of 100,000 tons of this desirable commodity.

Liquefied fluorine is one of the most powerful oxidizers known; all organic materials, and even water, are extremely reactive with fluorine. It is extraordinarily toxic and equally corrosive; contact with skin may produce burns which can be painful and difficult to heal. Despite its hostile character fluorine has been handled on a large scale for more than 24 years without a disabling injury.

It is important to realize that even the so-called "large scale" handling of liquefied fluorine has been restricted to a few major government contractors and that the large volume liquefied hydrogen work has been in the hands of a few government contractors and well-managed experienced large commercial suppliers. When a technology remains under the control of a responsible few and able organizations then self-regulation appears to produce a high level of safety, often sufficiently acceptable to require little more from regulatory bodies. The more widespread is the use of a dangerous material, the more need arises for controls with the force of law.

KIWI TNT

A controlled power excursion in a prototype nuclear rocket was carried out in January 1965 at the remote test site in Nevada. This was an important step towards predicting potential nuclear incidents of interest to the power reactor safety program. The confirmation of calculations by the experimental results obtained in this excursion has placed a high confidence level on all nuclear accident predictions.

It was particularly hard to predict the energy which is converted from heat energy to mechanical energy and relate this to chemical explosives or explosions that we know so much about.

Characteristics of Explosions

Kiwi-TNT was "exploded" in the sense of a violent disruption and dispersion of an originally intact object. In no way did that explosion resemble the conventional nuclear detonation.

Physical or chemical examples that might be used for comparison are explosions of dust, gas/air at atmospheric and elevated pressures, entrapped liquefied gases, boilers, high explosives, and black powder. This interesting safety study of a violent reactor excursion ran head-on into an international political complication.

Although planned in detail for several years and widely announced as a reactor safety experiment, and clearly of universal interest to a clean-power-needy world, it nevertheless was a power excursion that had explosive-like physical effects.

In 1963 a nuclear bomb test ban treaty had been signed by three principal nations: United States, United Kingdom and Union of Soviet Socialist Republics. Before long a total of 105 nations had already subscribed to this test ban treaty. Article 1 of the Test Ban Treaty states:

1. Each of the Parties to this Treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, <u>or any other nuclear explosion</u>, at any place under its jurisdiction or control:

   (a) in the atmosphere......

2. Each of the Parties to this Treaty undertakes furthermore to refrain from causing, encouraging, or in any way participating in, the carrying out of any nuclear weapon test explosion, <u>or any other nuclear explosion</u>, anywhere which would take place in any of the environments described...... in paragraph 1 of this Article.

While I, and others, may believe that the purpose of this treaty was to control testing of nuclear bombs, or bomb-like devices, nevertheless the effects of the reactor excursion described were clearly contrary to the words of the treaty.

This is certainly a strong reason why a research program with contrived similar reactor accident situations is not pursued. Of course, there are probably many other valid reasons.

But my observations on the public acceptance of new risk leads me to conclude that an understanding of the nature and consequences of potential misadventure may be as important as an accident-free experience. Too often does one see the concept of "maximum credible accident" become like the childhood boast of "my daddy can lick your daddy" or "I can figure out a credible accident more maximum than yours." Soon it is the credibility that gets strained and once this begins it is like yearning for the superfluous - without limit and of little use.

CONCLUSION

With the increased social awareness of risk in recent years has been the parallel development of the "prophets of doom." These are the individuals and groups who view science and technology as plunging ahead, guided only by their own internal value systems, applying new knowledge hastily without regard to human and esthetic consequences. In the force of this advance, according to the usual indictments, the individual is almost helpless.

There is little doubt of the truth in the accusation that science and technology have introduced new risks. I believe it is equally true that there has been a historical gain in safety through technical changes. To interrupt this gain by a demand for a demonstration of absolute safety would be a tragedy which I hope we could avoid.

ANALYTICAL APPROACHES TO RISK EVALUATION

by

Vernon L. Grose
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T tin Institute of Technology
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Mr. Grose's presentation was not available for inclusion in the Proceedings. However, much of the material that he presented orally is included in the attached paper which he presented in April 1971 to the Rail Transit Conference.

SYSTEM SAFETY IN RAPID RAIL TRANSIT

Vernon L. Grose

Every rail transit concept or design, by the time it is produced, contains a considerable level of inherent safety. Good engineering practice always includes the requirement of making a transit system safe. To state it another way, a competent transit system designer would find it more difficult to deliberately design a transit system to be unsafe than he would to make it safe.

Therefore, to separate "system safety" from rail transit system design is a difficult task. And it may be thought to be a totally unnecessary distinction! Those who understand and endorse the principle of totally integrated design could consider it most inappropriate to isolate and discuss a system characteristic such as safety. Further, it could easily appear that another "cult;" i.e., system safety, is being developed to further de-focus the already diffused responsibility of the transit system designer.

Could not the designer ask the question, "Am I to design the transit system without consideration of safety and then turn it over to some expert in safety to make it safe?" Why not simply motivate the designer to be more cautious and conscious of safety while he is designing if we want to be confident of safe operation of the transit system? Is it even possible to discuss safety of a transit system apart from the system itself?

These questions, illustrating the difficulty of separating safety from good solid engineering and manufacturing practice, lend credibility to the well-known cliche, "Safety is everybody's business." Unfortunately, safety often thereby becomes nobody's business.

If system safety is to be considered a separate and legitimate pursuit in the development, production and operation of a rapid rail transit system, conclusive answers to the following questions appear mandatory:

1. What is distinctly unique about "system safety" apart from all other transit system effort?

2. What traditional roles and/or activities, if any, must be revised, augmented or abolished to accomplish "system safety?"

3. Is "system safety" a technical activity, a transit system parameter (like cost or load density), an organizational function or a professional occupation?

4. How is "system safety" achieved; i.e., by edict, persuasion, activity, organization or technique?

5. When in transit system development is "system safety" pursued; i.e., during conceptual studies, design, development, test, production or operation? On a continuous basis or sporadically?

I will attempt to answer these questions in the context of a rapid rail transit system.

SYSTEM SAFETY DEFINED

The term "system safety" could mean to some people that industrial safety had "gone modern" and substituted the adjective system for industrial. That would be a most unfortunate assumption. System safety can be defined as

> "the optimum degree of hazard elimination and/or control within the constraints of operational effectiveness, time and cost, attained through the specific application of management, scientific and engineering principles throughout all phases of a system life cycle."

In the largest sense of the word, system safety embraces all conceivable interactions of operational and support equipment, personnel, facilities, and software which are used together as an entity and capable of performing and/or supporting a mass transit role.

System safety covers the total spectrum of risk management. It goes beyond the transit vehicle and associated operating procedures. Its scope includes attitudes and motivations of design, production, test and operations personnel, employee/management rapport, the relation of industrial and labor associations among themselves and with the Government, human factors in supervision, the interfaces of industrial

and public safety with design and operations, the interest and attitudes of top management, the effects of the legal system on accident investigations and exchange of information, the certification of critical operating personnel, political considerations, public sentiment and many other non-technical but vital influences on the attainment of an acceptable level of risk control.

System safety could also be considered a marriage of the systems approach with safety orientation. The "systems approach" was developed in a rather pragmatic manner.[1] Eight characteristics of this methodology have been identified as basic to the concept.[2] These characteristics are likewise basic to system safety: methodical, objective, quantitative or measurable, analytical, dependent on subsystems, elemental analysis in parallel rather than series, inputs/outputs in clear language, and self-containment.

Is system safety then a technical activity, a rail transit system parameter, a transit organizational function or a professional occupation? It is all four.

System Safety as a Technical Activity

There are a number of unique technical tasks dedicated solely to the achievement of rail transit system safety. These tasks are generally analytical in nature. Experience has shown that separate identity and performance of these tasks is essential for proper motivation during design and balanced emphasis on safety during transit system tradeoff studies.

Typical technical activity performed solely for system safety is the preparation of Fault Tree Analyses wherein extensive knowledge of the system, background in the history of previous hazards, analytical imagination in postulating a variety of system responses to a given hazard, and capability in preparing logic diagrams are all required. A Rail Transit Fault Tree for passenger fatality is included to show the basic logic diagramming used in this type of analysis. Note the use of "or" and "and" logic gates to connect events which ultimately lead to the primary undesired event (passenger fatality).

System Safety as a Rail Transit System Parameter

In its simplest form, a rail transit system can be considered to consist of a composite of equipment, personnel, facilities, and software which are used together as an entity to transform known inputs

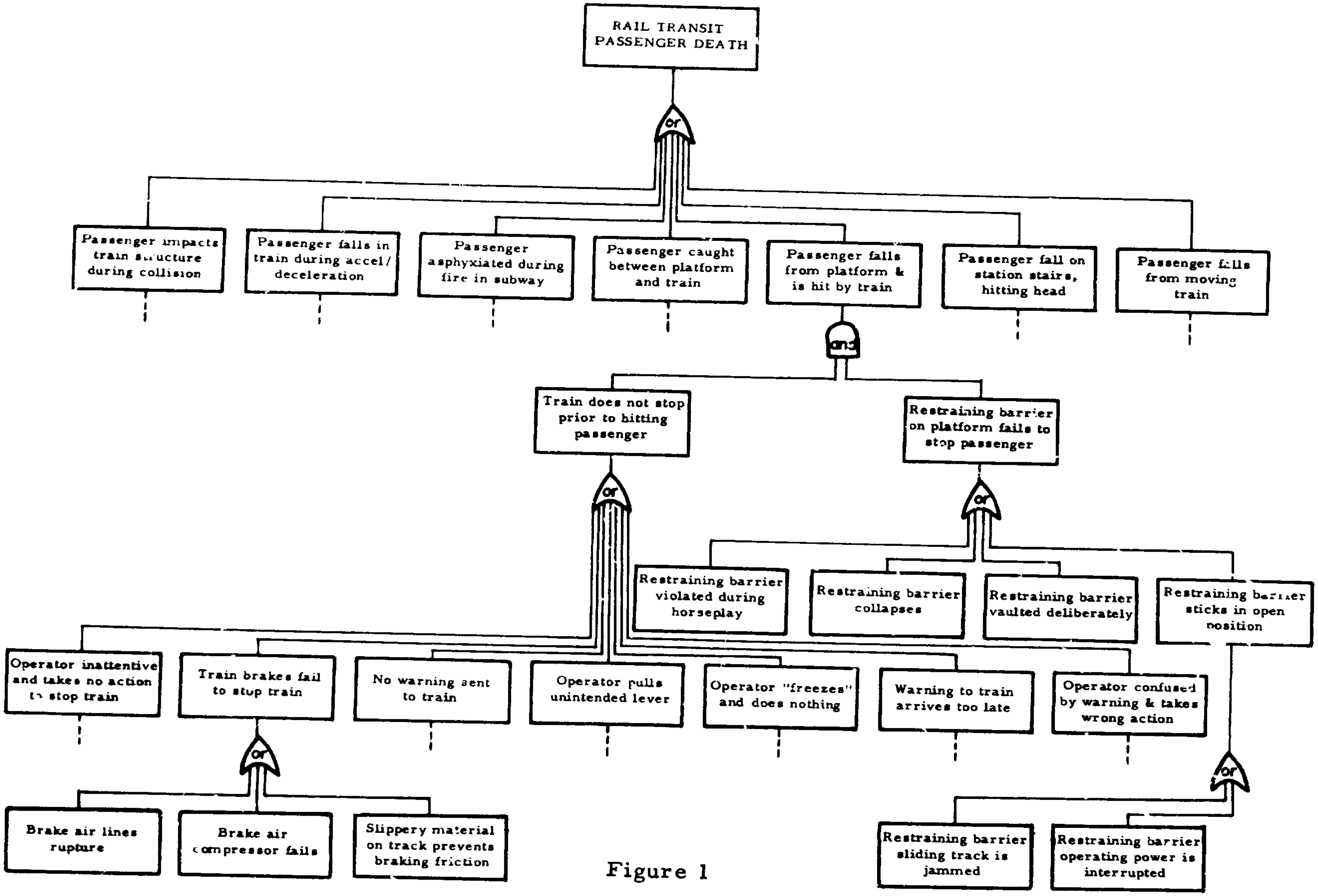


Figure 1

Rail Transit Fault Tree Illustration

into desired outputs. This transformation of inputs into outputs can be accomplished at varied levels of danger or risk. So a rail transit system can be described as a "safe" system just as it could be described as a "fast" or "costly" system. Therefore, just as top speed and cost are considered transit system parameters, so safety is also a transit system parameter.

Another proof that safety is a transit system parameter is that it is often traded against size, cost or performance in system tradeoff studies. This is not to say that safety is as measurable a parameter as size or cost. Nevertheless, it must be considered a system parameter.

The National Transportation Safety Board recently urged that safety be recognized by metropolitan transit officials as a system parameter.[3] In this context, the NTSB also recommended that MIL-STD-882[4] be adopted as a guideline for transit system safety activity.

System Safety as a Transit Organizational Function

Only in recent years have separately identified system safety groups been established in technological organizations. However, this separate designation has occurred as a result of a demonstrated need to focus attention organizationally on system safety. There are at least four reasons why a separate system safety organization can be justified:

1. System safety requires some highly specialized technical skills which can be acquired only through extensive formal education, training and experience. These skills are seldom available in classical line organizations. Also, time is generally not available to train line organization personnel in these unique skills.

2. The development, preparation and evaluation of system safety planning must be done on a continuous basis. Line and top management can then use the system safety organization as its "professional worrier" on behalf of system safety and is thereby free to concentrate on its primary operations.

3. The system safety organization has a continuing responsibility to provide service and counsel to all line organization personnel on system safety from their viewpoint of expertise.

4. Frequently, the system safety organization performs line organization work assignments on a loan basis in specialized

areas of capability which may not be available temporarily in line organizations.

Although the number of personnel assigned to a system safety organization and the reporting level in the organizational structure for system safety may both vary widely in practice, the purpose of a separate organizational identity for system safety is defeated if the organization is unable to maintain the proper balance of safety emphasis during the total life cycle of the transit system.

System Safety as a Professional Occupation

Due to the specialized system safety skills described earlier, there is increasing interest on the part of technical personnel in a profession of system safety. Colleges and universities now offer both undergraduate and graduate degrees in this field. Other indicators of a professional status such as specific technical literature in this discipline lend credence to the idea that system safety is and will continue to be a professional occupation.

It would be a mistake, however, to assume that even a majority of personnel working in the field of system safety would necessarily have to be professionals in that discipline. Since system safety is an inter disciplinary activity, it is an excellent assignment for specialists who have been narrow in their outlook to broaden their perspective. Therefore, those who staff system safety organizations should give serious consideration to rotation of line organization personnel into system safety for a reasonable length of time as part of their career development program.

SYSTEM SAFETY ANALYTICAL REQUIREMENTS

Analysis forms the backbone of system safety activity. The primary emphasis in system safety analysis is <u>inductive</u> thought; i.e., reasoning from particular data, facts or incidents to a general conclusion. <u>Deductive</u> reasoning; i.e., reasoning from a known principle to an unknown or from the general case to a specific case, is also employed to a lesser degree.

The ultimate purpose of any analysis is to aid the reaching of a decision. In the case of system safety analyses, the terminal decision is a management one-- "that the optimum amount of elimination and/or control of hazards in the transit system has been reached." To enable management to conclusively reach such a highly consequential decision, the system safety analyst has several requirements.

Knowledge of the Rail Transit System

There is an obvious danger that system safety analyses may be attempted without adequate knowledge and understanding of the specific transit system of interest. Any system safety analysis can be no better than the state of knowledge that the analyst possesses of the transit system under consideration.

Especially in the early stages of rail transit system design, specific and current system information is likely to be available exclusively within the design function or organization. Therefore, acquisition of design details by the system safety analyst may be difficult to obtain. Nevertheless, the analyst is obliged to become proficient in the knowledge of design if his analysis is to be useful.

Major rail transit criteria such as location of transit tracks (especially if adjacent to conventional railroads or public highways), transit train speed and spacing regulation, and inherent train car crashworthiness (together with associated escape criteria) have obvious inherent safety implications. Without question, the tradeoffs utilized to reach a decision for these criteria should include system safety considerations. In addition, however, far more subtle and extensive criteria are also of concern to the system safety analyst. He looks for possible interrelationships which could lead to hazards between such diverse factors as train acceleration/deceleration rates, location and intensity of station lighting, height of train car floor above track, the length of the train operator's shift, and the minimum track switching cycle. An experienced analyst in system safety is well aware that hazards are more likely at interfaces between subsystems than within any given subsystem itself.

During the conceptual phase of rail transit system design, the analyst can acquire knowledge of the design in various ways including personal contact with designers, studying specifications and working with breadboards and mockups. Another excellent source of design knowledge is the functional flow block diagram. This diagram shows the functional interrelationship of all elements in the transit system. It defines inputs and outputs as well as all the functions that the transit system will perform.

An additional aspect of transit system knowledge that is essential for system safety analysis is the operational environment to which the transit system will be subjected in service. This operational environment should not be limited to the natural environments such as

temperature, vibration, acoustics, and humidity. It should include all functional or operational aspects of the environment such as the type of person who will maintain the transit system, the number of hours that the train can be expected to operate without maintenance, the types of schedules and loads expected, and the anti-sabotage devices employed.

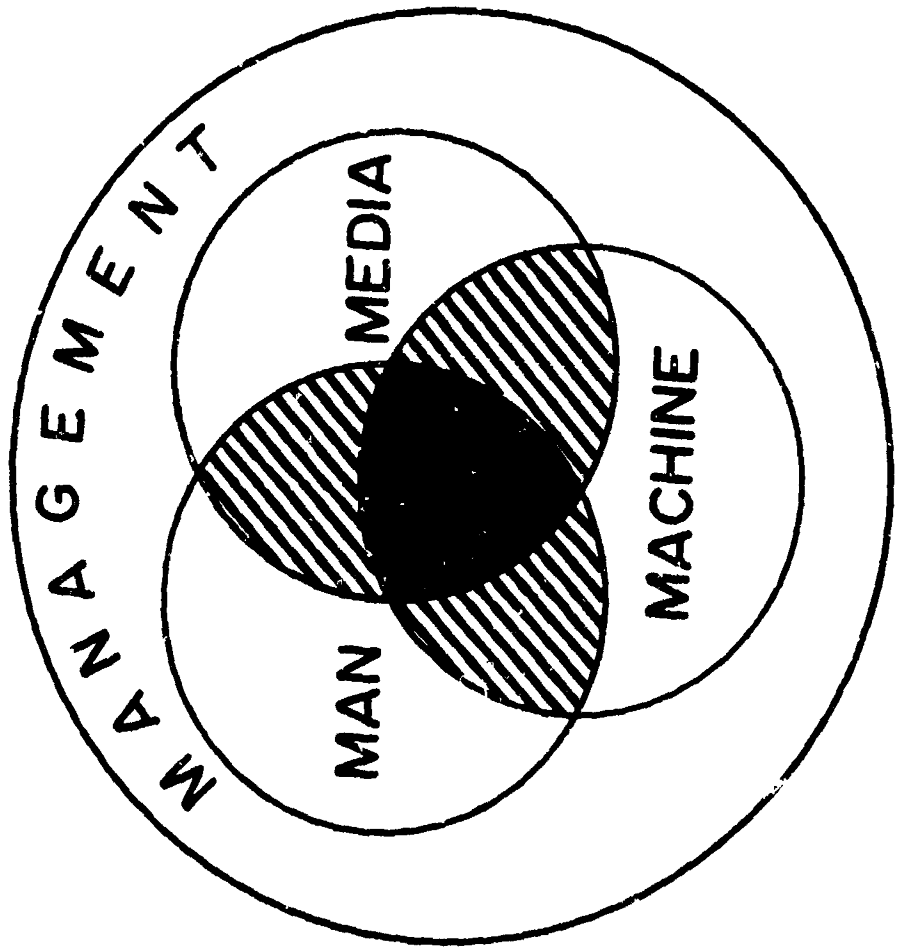
Knowledge of Rail Transit Hazards

The system safety analyst must not only be aware of the transit system design but also of those conditions which have been proven by past experience to be hazardous for rail transit. Hopefully, there exists within the transit agency and/or transit system contractor's files a library of historical data regarding such hazardous conditions.

Caution must be exercised to not limit the consideration of hazards to those conditions involving only hardware. Figure 2 is a Venn diagram which depicts the interrelationship of man, machine, media, and management. There are 15 different categories in that diagram; e.g., man/media, machine/management, media/man/machine/management, etc. Each one of the categories contains numerous transit system hazards which must be either eliminated or controlled. To illustrate a further breakout of categories or factors for hazards, Figure 3 represents another approach to stimulate the transit system safety analyst to consider as many sources of hazards as possible. As a warning, it should be obvious that Figure 3 ignores the interaction between the factors listed; e.g., possible interaction between passenger vehicle seat versus stand ratio and accident investigation procedures.

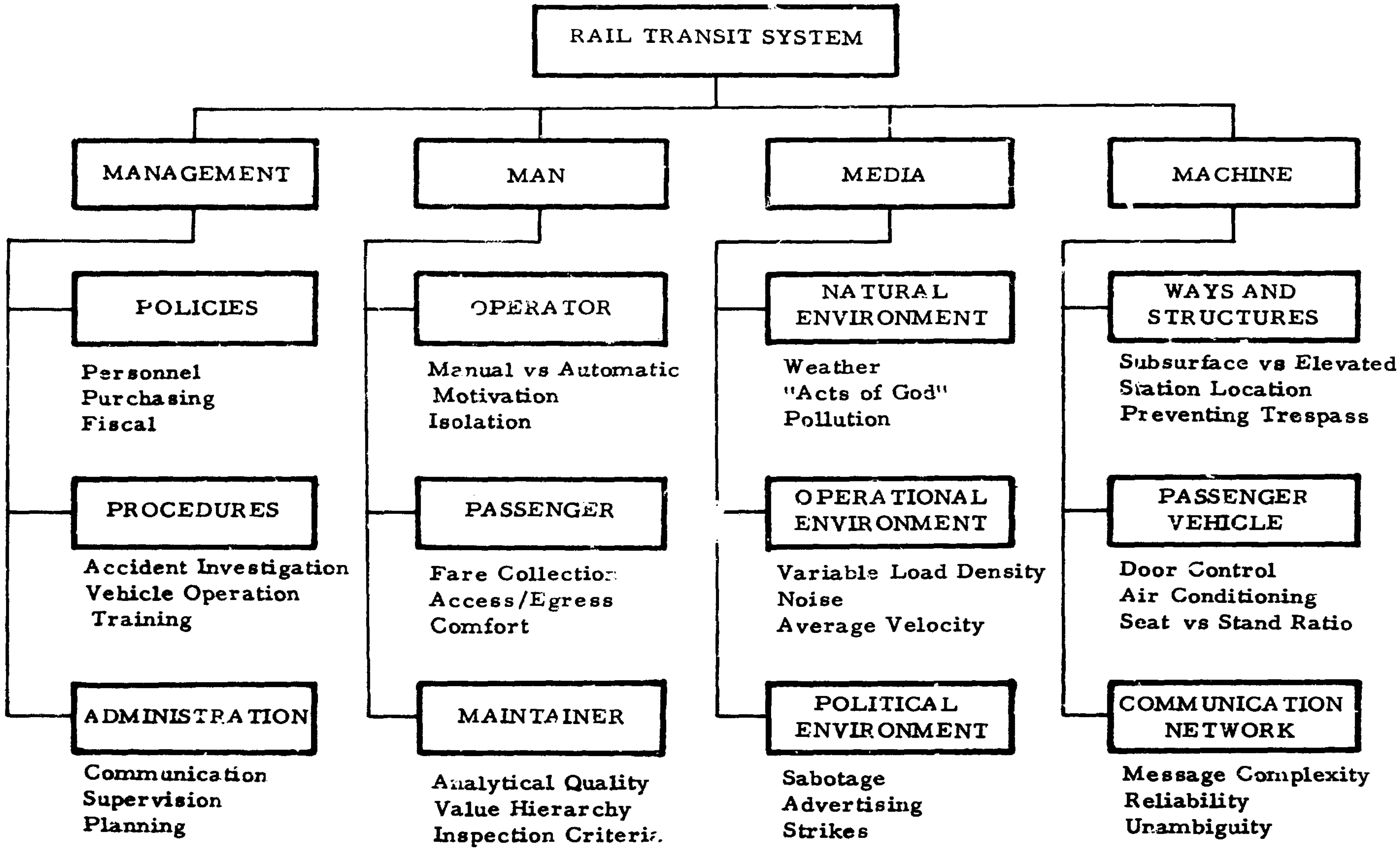
The technical literature on system safety contains many excellent references which list typical hazardous conditions. These listings of hazards should be consulted by the system safety analyst as a stimulant prior to and during his analysis. Very few accidents or incidents are uniquely new or first-time events. Almost without exception, they have happened in the past on similar equipment or in similar situations. The concept of "known precedent" emphasizes the fact that once an accident cause factor/potential has been demonstrated as being capable of causing an accident, it can be expected to occur with a given frequency and in much the same manner as errors tend to perpetuate themselves. It is the dedication to precluding the repetition of previous accidents that stimulates the system safety analyst to consider the causative factors or conditions of the past.

Aside from the now-popular trend toward referring to "noise" as one of our environmental pollutants, it might not occur to someone who



Interrelationship of System Safety Factors

Figure 2



TYPICAL SYSTEM SAFETY FACTORS IN RAPID RAIL TRANSIT

Figure 3

is unacquainted with system safety that "noise" in rapid rail transit systems is a prime source of hazards. The level and character of noise within a transit car are dependent on numerous factors including: the car construction, suspension system, wheels, condition of the car, type of track, method of attachment of track fastening, trackbed, speed of the car, and whether the car is travelling along straight track or moving in a curved path.[5] These factors vary in importance depending on whether the train is in a subway or above ground. Because sound is an important sense to the human, "noise" (a specific type of sound) can induce judgmental errors in passengers and operators as well as cause physical and mental sickness.

Using "noise" as a simple example then, it should be evident that any system safety analysis of rail transit which fails to list hazards resulting from noise would fall far short of useful in assuring hazard-free operation.

Methodology for Analysis

Once the system safety analyst has adequate knowledge of the rail transit system as well as comprehension of possible hazards that can be associated with such a system, he is ready to relate these two bodies of knowledge via a logical, methodical process. There are several types of analysis for system safety that have wide usage. Nevertheless, these analyses all contain certain common elements. They all have objectives, some focusing mechanism for decision, and a decision point or conclusion.

Analytical Objectives - As mentioned earlier, all system safety analyses must lead to a decision that the optimum amount of elimination/control of hazards in the rapid rail transit system has been reached. This decision implies that all hazard possibilities have been considered by the analyst. This objective of analysis, therefore, will be incomplete if the analyst fails to use his imagination and insight to include the most remotely possible hazards as well as those that are obvious.

Designers are frequently guilty of confusing possible hazards with probable hazards, thereby closing their minds to a large of number of hazards which are possible though improbable. This group of frequently ignored hazards is governed by Murphy's Law, i.e., "If a hazard can happen, it ultimately will happen."

Another objective of analysis is to provide a clearly discernable rationale which can be objectively evaluated by someone other than the analyst. If this objective fails to be met, there is no way to effectively

measure the influence of subsequent design changes on the transit system safety. Further, the value of the conclusions reached by the analysis will be solely dependent on the integrity and capability of the analyst.

Focusing Mechanism - Obviously, there are not enough resources in any specific rapid transit project to eliminate and/or control all the possible hazards in the transit system. Therefore, there must be some method for screening, ranking, or filtering the hazards for those of the highest consequence to operation of the transit system. This ranking process provides transit management with a yardstick which is focused on the safety problems of greatest magnitude. Then management can concentrate the application of resources on those specific problems.

One practical way by which this ranking or focusing can be accomplished is by first evaluating all hazardous conditions when applied to the transit system and classifying the severity of the hazards. Four hazard levels are defined and established in MIL-STD-882 for this purpose.[4] These four categories cover the spectrum of consequence from negligible to catastrophic situations.

This classification is only the first step in the focusing process. Two additional measures have to be applied before top management can authorize expenditure of resources to eliminate and/or control the hazards. The first of these two is the probability or likelihood of the hazard occurring. If the hazardous condition is likely to be very prevalent, action should be taken by management to eliminate or control the hazard even if the hazard level of severity is less than catastrophic.

The second of the two additional parameters is the amount and type of resources required to eliminate or control such hazards. If a hazard can be reduced or eliminated for a very small amount of money or effort, management is abliged to consider this hazard even if it is of relatively small consequence and likelihood.

In summary, then, focusing for management decision is accomplished by simultaneously considering three parameters of any hazard:

1. The consequence or severity of this particular hazard, if it occurs during the operation of the transit system.

2. The likelihood or probability of this hazard occurring.

3. The amount and type of resources required to eliminate or control this hazard.

A range of values for these three parameters is listed in Tables 1, 2, and 3.

Table 1 is an example of how the four hazard levels of MIL-STD-882 should be specifically interpreted for a particular rapid rail transit system. Note that each hazard level must be interpreted in terms of system objectives, functional capability and personnel safety. All possible hazards in the transit system must be measured for severity against these four hazard levels, and one of the four code letters in Table 1 must be assigned to each hazard.

Table 2 provides a range of probabilities for any given hazard occurring. The same procedure used in selecting a code letter from Table 1 is used to select a code letter in Table 2, with every possible hazard also being assigned one of the four probability code letters.

Table 3 cannot be as readily applied as Tables 1 and 2 because there must be an intermediate conversion of various resources (e.g., policy, procedures, manpower, technology, facilities, materials, and schedule) into a dollar equivalence before a code letter can be selected. Nevertheless, it is imperative to estimate the amount of resources that will be required to eliminate/control every possible hazard. Therefore, a third code letter from Table 3 must be assigned to each hazard under consideration.

Once three code letters (one each from Tables 1, 2, and 3) have been assigned to each possible hazard, the focusing is achieved by combining the three individual code letters into one overall index of significance. The Hazard Totem Pole of Table 4 lists these code combinations in order of importance or significance for management decision.

Decision Point - When all possible hazards in the rapid rail transit system have been focused or ranked for significance in a Hazard Totem Pole, the stage is set for management decision concerning the hazards. Obviously, there are never enough resources to completely eliminate every possible hazard. For this reason, management must set a "decision point" or cutoff level in the Hazard Totem Pole. This decision point is drawn at that significance ranking code below which all remaining hazards will be ignored. The decision point may be established by either (1) the reduction of hazard significance to a level which management considers adequate or (2) the depletion of resources available for application to hazard elimination or control.

Table 1

HAZARD SEVERITY FOR RAIL TRANSIT SYSTEM

CODE	MIL-STD-882 HAZARD LEVEL	EFFECT ON SYSTEM OBJECTIVES	EFFECT ON FUNCTIONAL CAPABILITY	EFFECT ON PERSONNEL SAFETY
A	Catastrophic	Rail transit rendered impossible-- Mission is lost	No portion of rail transit system can be salvaged-- Total loss	Personnel suffer death or multiple injuries by factors in Code B
B	Critical	Rail transit impaired seriously-- Mission accomplished only by auxiliary methods	Two or more major sub-systems of rail transit are damaged-- This condition requires remote depot maintenance	Personnel injured either: (1) operating the transit system, (2) maintaining the system, (3) being transported by system, or (4) being in vicinity of the transit system
C	Marginal	Rail transit is possible by utilizing available redundant operational options	No more than one component or subsystem damaged. This condition is either repairable or replaceable within one hour on site	Personnel-injuring factors in Code B can be controlled by either automatic devices, warning devices or special operating procedures
D	Negligible	No measureable effect on rail transit mission	No apparent damage to the rail transit system	No injury to personnel

Table 2

HAZARD PROBABILITY FOR RAIL TRANSIT SYSTEM

CODE	DESCRIPTION OF SITUATION
J	Hazard of interest will occur within 10 cumulative hours of operation
K	Hazard of interest will occur within 100 cumulative hours (4 cumulative days) of operation
L	Hazard of interest will occur within 1000 cumulative hours (41 cumulative days) of operation
M	Hazard of interest will occur within 10,000 cumulative hours (14 cumulative months) of operation

Table 3

HAZARD ELIMINATION/CONTROL RESOURCES

CODE	CALCULATED DOLLAR EQUIVALENCE
P	Less than $1000 required to eliminate/control this hazard
Q	$1000 - 10,000 required to eliminate/control this hazard
R	$10,000 - 100,000 required to eliminate/control this hazard
S	Over $100,000 required to eliminate/control this hazard

*Calculated dollar value of all resources (revision of policy, procedures, manpower, dollars, technology, facilities, materials, and schedule) required to either eliminate or control the hazard of interest.

Table 4

HAZARD TOTEM POLE

Hazard Significance Ranking[1]	Code Combination[2]			Number of Rail Transit System Hazards
	Hazard Severity	Hazard Probability	Hazard Resources	
1	A	J	P	3
2	A	J	Q	None
3	A	K	P	1
4	B	J	P	16
5	A	J	R	7
6	A	K	Q	None
7	A	L	P	4
8	B	J	Q	22
...	...	...	...	...
64	D	M	S	2

[1]Because there are 4 codes for each of the 3 hazard parameters, the Hazard Totem Pole must contain 64 code combinations; i.e., 4x4x4. The ordering or ranking of the code combinations in this example is such that the first combination (AJP) is the most significant and code combination DMS is least significant to rail transit system management. This ordering can be varied depending on the criteria one sets for relative significance between hazard severity, probability and resources. In the ordering illustrated, all three parameters were equally weighted but preference was given first to severity, then probability and finally resources. Both weighting and preference of codes should be established prior to preparing a Hazard Totem Pole.

[2]The codes being combined are those from Tables 1, 2, and 3.

To illustrate this decision point, management could decide that it will eliminate and/or control all hazards in the first 7 levels or categories in the Hazard Totem Pole shown in Table 4; i.e., all the AJP, AJQ, AKP, BJP, AJR, AKQ, and ALP hazards. This would mean that 31 specific identified hazards will require resources to be allocated by management for purposes of eliminating or controlling the hazards. (Note that there were no AJQ or AKQ hazards.)

It is important to also note that while management will be committing resources for the first 7 levels in the Hazard Totem Pole, they will, by this very action, be deliberately ignoring all remaining 57 levels in the Hazard Totem Pole. Therefore, the decision point in system safety analyses is that point which separates action from inaction regarding hazards.

RESOLUTION OF HAZARDS

The primary purpose of the system safety concept is to consider the elimination of hazards in the rapid rail transit system during the design phase, thereby precluding, in the most economic manner, loss of life and property. While the analytical effort discussed thus far must precede design integration of system safety, it is only preparatory. Analysis, per se, cannot accomplish any increase in the safety of the transit system.

Assuming then that a thorough system safety analysis of the transit system design has been performed, that a Hazard Totem Pole has been prepared, and that engineering management has established a decision point in the Hazard Totem Pole, the actual effort toward achievement of system safety can begin.

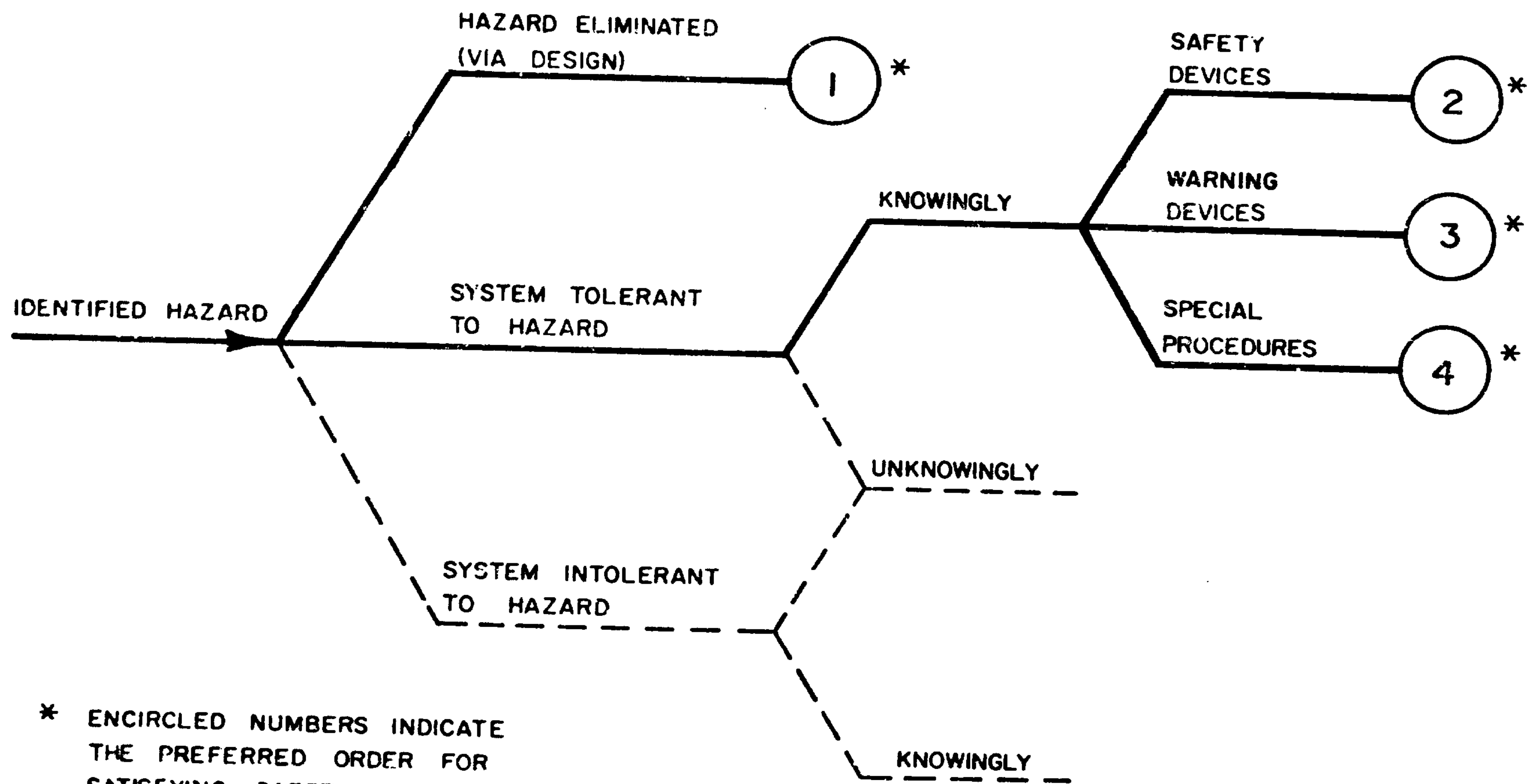
The first step in the achievement of system safety must be taken by the transit system designer. He must resolve whether he is going to totally eliminate the possibility of each hazard or whether he will institute control measures in the design to assure that such hazards can be tolerated by the transit system.

MIL-STD-882 describes a series of actions for satisfying safety requirements of a system design. The series is known as "system safety precedence." This precedence is shown in logic diagram format in Figure 4.

The first and most desirable alternative (#1 in Figure 4) is to eliminate the identified hazard completely by means of appropriate safety

Figure 4

SYSTEM SAFETY LOGIC & PRECEDENCE



* ENCIRCLED NUMBERS INDICATE THE PREFERRED ORDER FOR SATISFYING SAFETY REQUIREMENTS

design features such as fail-safe or redundant approaches. If elimination of a hazard is impossible or uneconomical, the next step is to make the transit system tolerant to the hazard. This can be done knowingly or unknowingly. However, system safety methodology demands that hazard tolerance be knowingly designed into the transit system if the hazard cannot be eliminated.

Three alternatives for making a design tolerant to identified hazards are stipulated in MIL-STD-882 in a descending order of desirability. The first of these accommodative approaches to hazards (#2 in Figure 4) is to reduce the significance of the hazard through the use of appropriate safety devices. These devices, placed at critical junctures in the transit system, should not require human intervention or cognizance but should operate automatically if the specified hazardous condition arises. An example of this approach might be the application of collision-avoidance radar on trains which would automatically sense the closing rate between two trains (without involvement of an operator) and apply brakes in adequate time to prevent collision.

The next choice shown in Figure 4 that should be considered (#3) is to accommodate the occurrence of an identified hazard by placing warning devices at those points in the transit system which are susceptible to that hazardous condition. These devices would obviously require human intervention to respond to the warning produced by the device. Audio or visual indicators are commonly used in this respect, but there is a limit on the number of such devices that can be effectively employed in complex situations.

The final and least desirable approach to satisfying requirements for safety in the transit system is to prepare, disseminate, and enforce special operating procedures regarding the identified hazardous condition. Procedures are to be viewed as a weak link in the achievement of system safety because of the inability to verify the communication of the procedure to the person who must operate in accordance with it.

With the exception of those hazards which can be eliminated very economically early in the design stage, the four possible alternatives shown in Figure 4 are numbered in a hierarchy of decreasing effectiveness as well as decreasing cost. Therefore, the lower the number in the hierarchy, the more effective the choice will be in satisfying transit system safety requirements even though there may be higher cost associated with the action.

Figure 4 also illustrates that the transit system design can be

tolerant to identified hazards without the knowledge of either designers or operators. This area of ignorance about the hazard tolerance is not desirable and is therefore shown in dotted lines.

A third possibility for identified hazards is that the transit system can be intolerant to such hazards. This is a vital area of system safety concern and attention. As shown in Figure 4, transit system intolerance to a particular hazard may occur either with the cognizance of those who design, build and operate the system or in their ignorance. Hazards to which a transit system is knowingly intolerant are commonly described as "accepted risks" and should be among those hazards that fall below the decision point in the Hazard Totem Pole.

CONCLUSIONS

To briefly summarize this paper, the five questions postulated in the introduction could be answered as follows:

1. What is distinctly unique about "system safety" apart from all other transit system effort?

   Answer: It is a professional activity, free from the pressures of line organization and solely dedicated to "worrying" about hazards, real and potential, that could prevent the transit system from accomplishing its full and intended mission.

2. What traditional roles and/or activities, if any, must be revised, augmented or abolished to accomplish "system safety?"

   Answer: First, the "system" aspect of system safety demands a revision in planning and management by insisting on a "womb-to-tomb" viewpoint from the very outset of system design. Second, by covering the total spectrum of risk management, system safety embraces not only the concept of "freedom from danger" but also "freedom from loss of any resource."

3. Is "system safety" a technical activity, a transit system parameter (like cost or load density), an organizational function or a professional occupation?

   Answer: It is all four.

4. How is "system safety" achieved; i.e., by edict, persuasion, activity, organization or technique?

Answer: Depending on when in the life cycle of the transit system it is instituted, system safety will exhibit one of these methods to a greater extent than the rest. However, it would be accurate to say that all five methods are utilized to some extent in any system development and operation.

5. When in transit system development is "system safety" pursued; i.e., during conceptual studies, design, development, test, production or operation? On a continuous basis or sporadically?

Answer: The earlier that system safety emphasis and activity occurs, the higher the safety is likely to be per dollar invested. System safety activity should ideally occur in all phases of system life, from conception to retirement. The effort should continuous, not necessarily at the same level of effort, through the entire life cycle of the transit system.

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ABOUT THE AUTHOR . . .

Vernon L. Grose joined Tustin Institute of Technology as Vice President in 1966 after fifteen years as an engineer, author, lecturer, and aerospace executive. His responsibilities with Tustin Institute include all management curricula as well as system technology studies.

While a member of the Applied Physics Staff of The Boeing Company, he wrote the development test program for the Minuteman ICBM. From 1959-62, he was Director of Reliability and a member of the Executive Staff of Litton Industries where he also was Program Manager of Project SPARR, an Air Force program of basic and applied research on space system problems.

His involvement in all three manned space programs-- Mercury, Gemini, and Apollo-- began at Northrop in 1962 where he was Director of Applied Technology. He continued his involvement in space systems as an Engineering Chief at Rocketdyne until he joined Tustin Institute.

Dr. Wernher von Braun appointed him to the NASA Safety Advisory Group for Space Flight in 1969. An Associate Fellow of the American Institute of Aeronautics and Astronautics, he served on the AIAA System Effectiveness and Safety Technical Committee from 1967 through 1970. He is also a Senior Member of the Institute of Electrical and Electronics Engineers and Secretary-Treasurer of the IEEE System Science and Cybernetics Group.

As a faculty staff member of the University of Southern California, he co-pioneered the first graduate level course in System Safety in 1967, as well as teaching graduate courses in system engineering in Europe for USC. He is currently the Principal Lecturer and Course Coordinator for System Safety at the School of Engineering and Applied Science of The George Washington University in Washington, D. C.

His consulting clients in system technology and management include IBM, Litton Industries, General Electric, National Transportation Safety Board (Bureau of Aviation Safety), Teledyne Systems, Doubleday Multimedia, Northrop Corporation, and the City of Burbank (on urban problems). Over 25 journals and periodicals have published his papers, and he is listed in <u>WHO'S WHO In The West</u> and <u>Dictionary of International Biography</u>.

DECISION RISK ANALYSIS:

Risk Theory

by

Jerome H. N. Selman
Member, Operations Research Group
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DECISION RISK ANALYSIS

Risk Theory

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This paper presents a conceptual framework applicable for identifying and quantifying the risk elements in the transportation of hazardous materials. The primary aim of Decision Risk Analysis is to prescribe how a decision maker should choose among alternate courses of action when the outcomes of such a choice depend on events that are not known with certainty. Decision Analysis which is variously defined as a methodology for analyzing complex decision problems, a way of formalizing common sense, a theory of rational behavior in the face of uncertainty---has grown from a mathematical toy to an important aid of the decision maker. Ronald A. Howard of Stanford University predicts that "in the future both technical and managerial decision makers will employ formal logical methods in decision making. The transition probably will be painful."

The innovation of Risk Analysis is the professional presentation to the decision maker of models of the system which permit him to input his own personalistic, subjective or intuitive judgments into the analytical or quasi-analytical structure to arrive at credible decisions in which he feels confident.

From the point of view of the decision maker, the program that has been risk-analyzed should have no surprises. The

Risk Analysis should have addressed all critical areas, it should have raised all sorts of embarrassing questions, like the "Devil's Advocate" of the Jesuits who assembled the best negative arguments. If the proposal cannot withstand such an attack as a test of the decision, action is postponed. The devil's advocate is not passing judgment on a program, but simply seeing to it that all adverse points are considered in a responsible manner.

A working definition of Risk Analysis might be "a systems analysis (approach) to risk" which implies that the goal is to identify the risk areas, reduce or eliminate the risks, improve the chances of successful accomplishment of the mission. In the Department of Defense the term means the identification of the uncertainties involved with the time (schedule)/cost/technical performance (quality) measures of the system. Decision Risk Analysis is the method whereby the uncertainty measures of three-dimensional space are traded off to find an optimal, or satisfactory alternative. The output of decision analysis is a quantitative assessment of which alternative(s) should be selected. A number of techniques of Operations Research, Systems Analysis, Management Science, are normally used in forming a decision analysis model of a complex system. The Delphi procedures (for group consensus of experts) and the Standard Gamble or Lottery technique are often used for

encoding judgment into (subjective) probability distributions associated with uncertain outcomes for 3-space. The Decision Tree technique is a useful schematic summary for structuring and evaluating the alternatives appropriate to a set of circumstances involved with a sequence of decisions required for, say, the transportation of dangerous goods. A "tree" is constructed by enumerating and tracking through from start to finish the outcomes of each possible decision that can be made at decision points along the way. The payoff of each route (branch, sequence of decisions) through the tree is calculated along with the system risk in 3-space. Probability theory and utility theory are used to tie this all together and determine the expected project payoff and associated risk.

Risk is ubiquitous. The precise definition is dependent upon the orientation of the disciple under focus---economics, statistics, business, or in the common vernacular. Risk levels are difficult to assess. For airline insurance, for example, is $1.00 premium for a $40,000.00 principal sum (for a one-way trip) reasonable, or exorbitant? Does the fact of one fatality per 5 million air trips have any physical or probabilistic meaning on making a decision?

A sharp distinction should be made between decisions and outcomes in the decision process. A good outcome is a desirable outcome. A good decision is one logically consistent with

information and preferences. The purpose of Decision Risk Analysis is to increase the likelihood of good outcomes by making good decisions.

Some assertions concerning Decision Risk Analysis were made by R. A. Howard, including the decision/outcome dichotomy. The current trend is to place the blame/praise where it should properly belong---on the decision process, not on the outcome.

Much attention has been given recently in the Department of Defense to the nature of risk in evaluating major programs, as it has become increasingly clear that the methods and practices used in the acquisition and control of systems and programs have accounted very poorly for risks. Due to the cost growth, time growth and performance degradation upon major weapons systems, the Aerospace Industries Association stated a need for more formal methods of risk assessment. On 31 July 1969, Deputy Secretary of Defense David Packard wrote to the Secretaries of the Army, Navy, and Air Force: "I would, therefore, like each of you to assure that:

> Areas of high risk are identified and fully considered;
> Formal risk analysis on each program is made:
> Summaries of these are made part of the back-up material for the program."

He later, on 28 May 1970, offered guidance on how risks inherent in new programs can be minimized:

> 1. RISK ASSESSMENT. Make a careful assessment of the technical problems involved and a judgment as to how much effort is likely to be necessary in finding a solution

that is practical. A careful look at the consequence of failure, even of 'low risk' program elements, is also critical.

2. SYSTEM (& HARDWARE) PROOFING. Perform enough actual (eng) design and component testing in the conceptual development stage to demonstrate that the technical risks have been eliminated or reduced to a reasonable level. Component or complete system prototyping, or back-up development, are examples of this. Pilot studies, feasibility studies of competing approaches are other examples.

3. TRADE-OFFS (RISK AVOIDANCE). Consider trade-offs not only at the beginning of the program but continually throughout the development stage; program risk and cost are dependent on practical trade-offs between stated operating requirements and engineering design.

Of the three groups of professional decision makers---business executives, politicians, and military officers---only the military have a formal doctrine of decision, known as "the estimate of the situation." Its five formal steps are:

- Determination of the mission.
- Description of the situation and courses of action.
- Analysis of opposing courses of action.
- Comparison of own course of action.
- The decision.

However, due to the limited applicability to two-person situations (e.g., battlefield problems), even military decisions are made with that intangible something known as military judgment, just as business decisions are made with business judgment.

Businessmen are remarkably candid about their own inability to analyze the act of decision. In a 1955 survey by Fortune as to how businessmen make decisions, no rules were indicated:

> Cox (President, Kennecott Copper): I don't think businessmen know how to make decisions. I know I don't!
>
> Fairless (ex-Chairman, U. S. Steel): You don't know how you do it, you just do it.
>
> McCaffrey (President, International Harvester): It's like asking a professional baseball player to define the swing that has always come natural to him.

A surprising number of executives---perhaps of the dynamic (vectoral) type of Professor John Mihalasky in his talk on Precognition in Decision Making---believe that the outcome of their decisions is certainty.

> Gilbert (President, Seattle Gas Co.): It sounds bad in print, but I am always sure of the results when I make an important decision.

Other decision makers talk about risk:

> Willkie (President, Pacific American Fisheries): Very few things are black and white; mostly grey. I don't consider certainties ever. But, certainly, I consider the good probabilities. I'd say, .300 is a good batting average in our business.
>
> Doan (President, Dow Chemical): I estimate 15 plus percent error occurs in the best decisions.

The latest current guidelines on decision risk analysis offers the following advice which is quite similar to the procedures for systems analysis, for the military "estimate" of a situation" and more generally, the scientific method:

1. Define just what the problem is (this may be a major effort in some instances).

2. Establish alternatives with their appropriate terminal milestones. (It is important to ferret out all possibilities. An alternative should not be ignored because it does not appear to be a likely future choice.)

3. Lay out all the possible chain of events leading to the terminal milestone for each alternative.

4. Determine the possible outcomes at the terminal milestone for each alternative in terms such as time, cost, and/or performance.

5. Assess the probability of achieving each of these outcomes. (One should place emphasis on quantifying the uncertainty in those events shown by sensitivity analyses to be driving forces. This effort may be facilitated by developing probabilistic performance models relating component performance to overall performance and utilizing certain computer models which relate total time and cost distributions associated with the terminal milestone to the time and cost distributions of events leading to the terminal milestone.)

6. Conduct trade-off analyses to provide the basis for selecting a preferred alternative.

7. Determine the sensitivity of this selection to variations in trade-off criteria and sensitive events.

8. Present the final study to the decision maker in a concise logical fashion emphasizing the rationale behind the selection of the preferred alternative. (It is important to highlight the events to which the outcome of each alternative is sensitive.)

The idea is to make the network exhaustive in the sense that all feasible alternative paths or outcomes are identified and listed; the tree can then be pruned in a heuristic manner so that only realistic (practical) alternatives remain. Values as well as probabilities can be input to the structure so that the decision maker (via sensitivity analysis) can see the impact of changes in the variables. After all the hocus-pocus of manipulating the decision tree model, the decision to be made is clear. For example, to select alternative X would be equivalent to taking a chance on a (roulette) wheel where the probability of success is, say, 80% and failure, 20%. The question then becomes---who will make that decision? Who is the decision maker?

RISK ANALYSIS

("SYSTEMS ANALYSIS OF RISKI")

IDENTIFIES:

- ANTICIPATED PROBLEM AREAS
- CONSEQUENCES OF FAILURE
- LOW AND HIGH RISK PROGRAM AREAS
- REQUIREMENTS VIS-A-VIS STATE-OF-ART
- ADEQUACY OF TIME FOR PROGRAM
- SUFFICIENCY OF BUDGET
- OPTIMUM ALLOCATION OF RESOURCES
- DATA GAPS
- NEEDED STUDIES AND CONCEPTS
- SENSITIVE/CRITICAL FACTORS

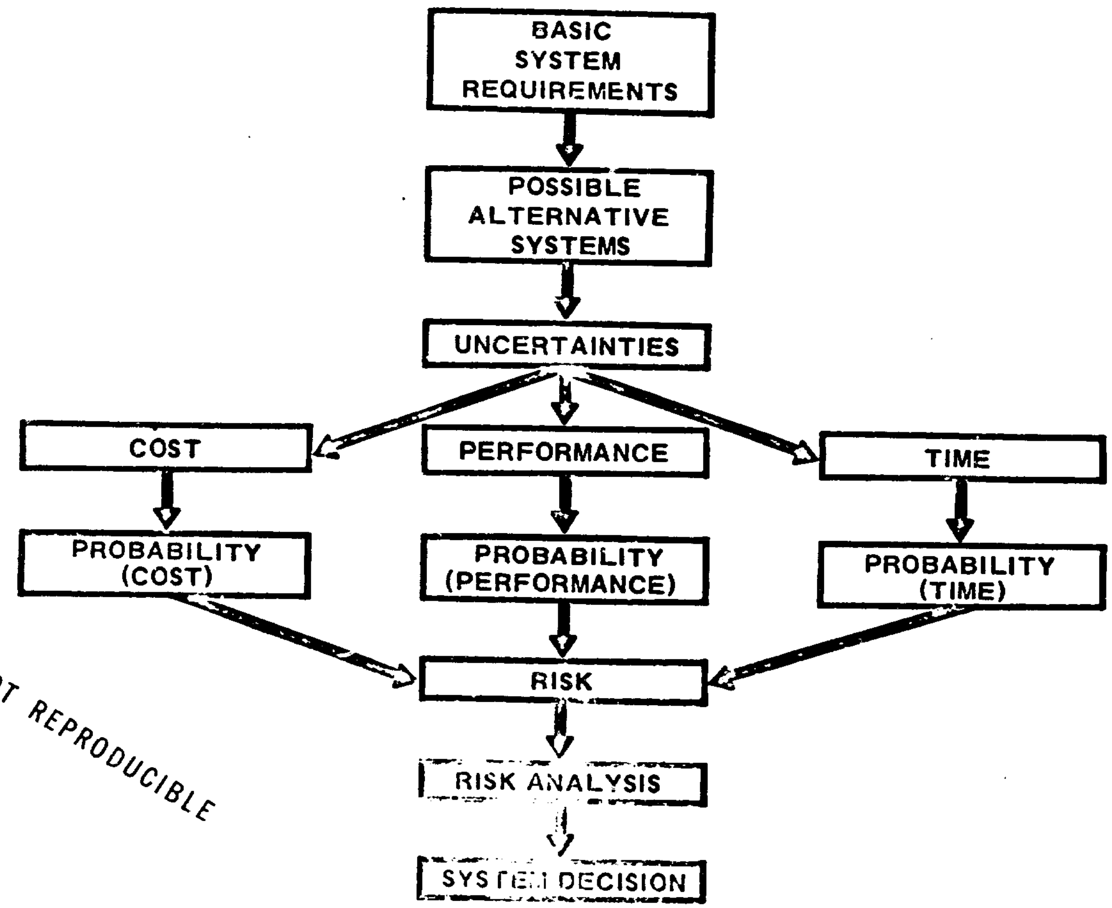
RISK ANALYSIS

ASSERTIONS*

- THE PROCESS OF DECISION-MAKING IS AT THE HEART OF MOST TECHNICAL, BUSINESS AND GOVERNMENTAL (RISK ASSESSMENT) PROBLEMS
- DECISION-MAKING REQUIRES THE STUDY OF UNCERTAINTY
- UNCERTAINTY CAN ONLY BE STUDIED FORMALLY THROUGH PROBABILITY THEORY
- PROBABILITY IS A STATE OF MIND, NOT OF THINGS
- ALL PRIOR EXPERIENCE MUST BE USED IN ASSESSING PROBABILITIES
- DECISION-MAKING REQUIRES THE ASSESSMENT OF VALUES AS WELL AS PROBABILITIES
- DECISIONS CAN ONLY BE MADE WHEN A CRITERION IS ESTABLISHED FOR CHOOSING AMONG ALTERNATIVES
- THE IMPLICATIONS OF THE PRESENT DECISION FOR THE FUTURE MUST BE CONSIDERED
- WE MUST DISTINGUISH BETWEEN A GOOD DECISION AND A GOOD OUTCOME

*R. A. HOWARD, THE SCIENCE OF DECISION-MAKING. REPRINTED BY THE JOINT ENGINEERING-ECONOMIC SYSTEMS PROGRAM, STANFORD RESEARCH INSTITUTE

BASIC SCHEME FOR RISK ANALYSIS



FACTORS WHICH VARY THE RISK

- RESOURCE LIMITATIONS:
  - LACK OF DEFINED REQUIREMENTS
  - INSUFFICIENT QUALIFIED PERSONNEL
  - LACK OF KNOWLEDGE
  - LACK OF PROVEN COMPONENTS
  - LACK OF DESIGN MARGINS
  - LACK OF TIME
  - INSUFFICIENT FUNDS

- MANAGEMENT PRACTICES:

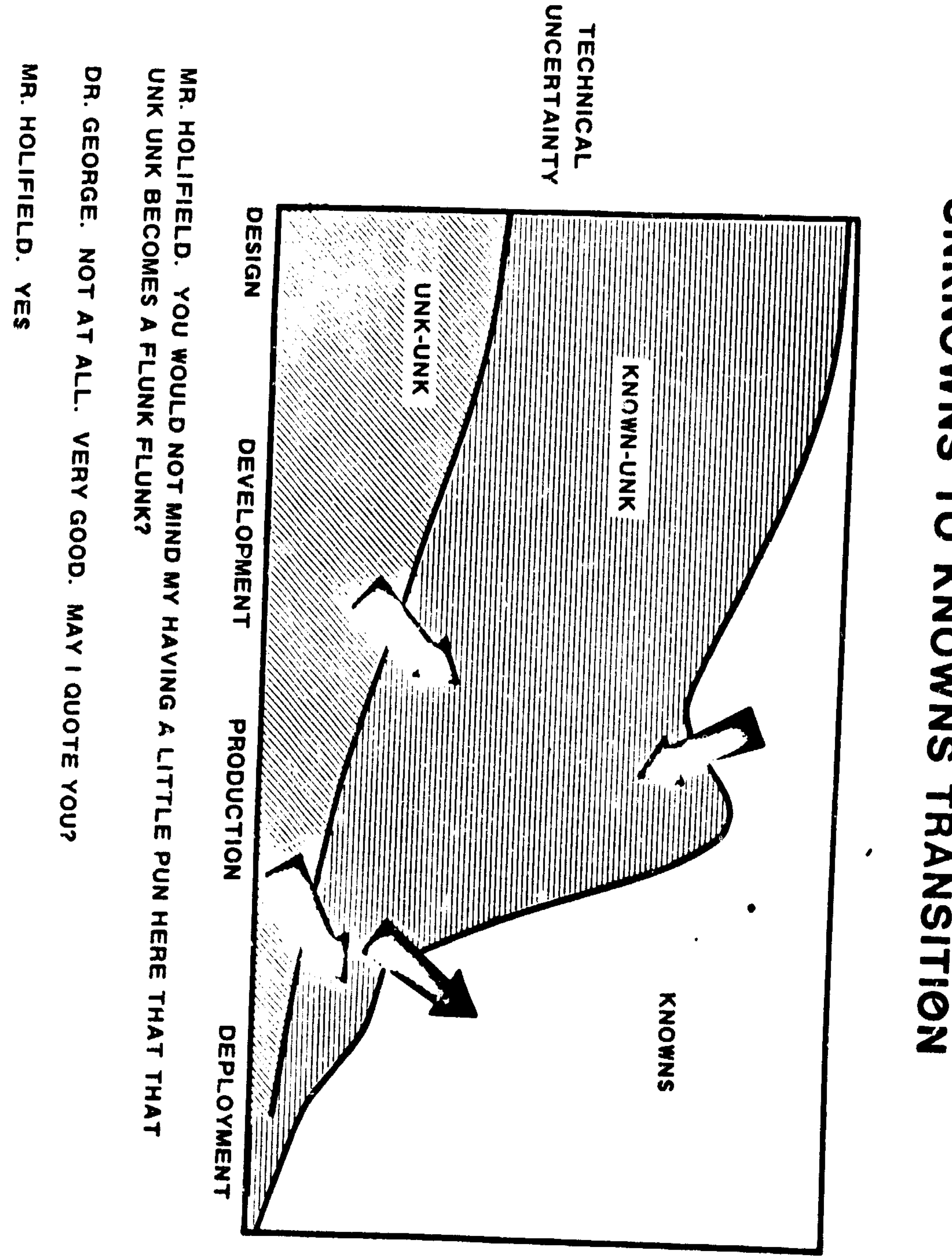
  EXTENT TO WHICH PROVEN PRACTICES ARE USED IN THE AREAS OF

  - ENGINEERING
  - MANUFACTURING
  - QUALITY CONTROL
  - PROGRAM

UNCERTAINTIES CONTRIBUTING TO TIME, COST AND PERFORMANCE

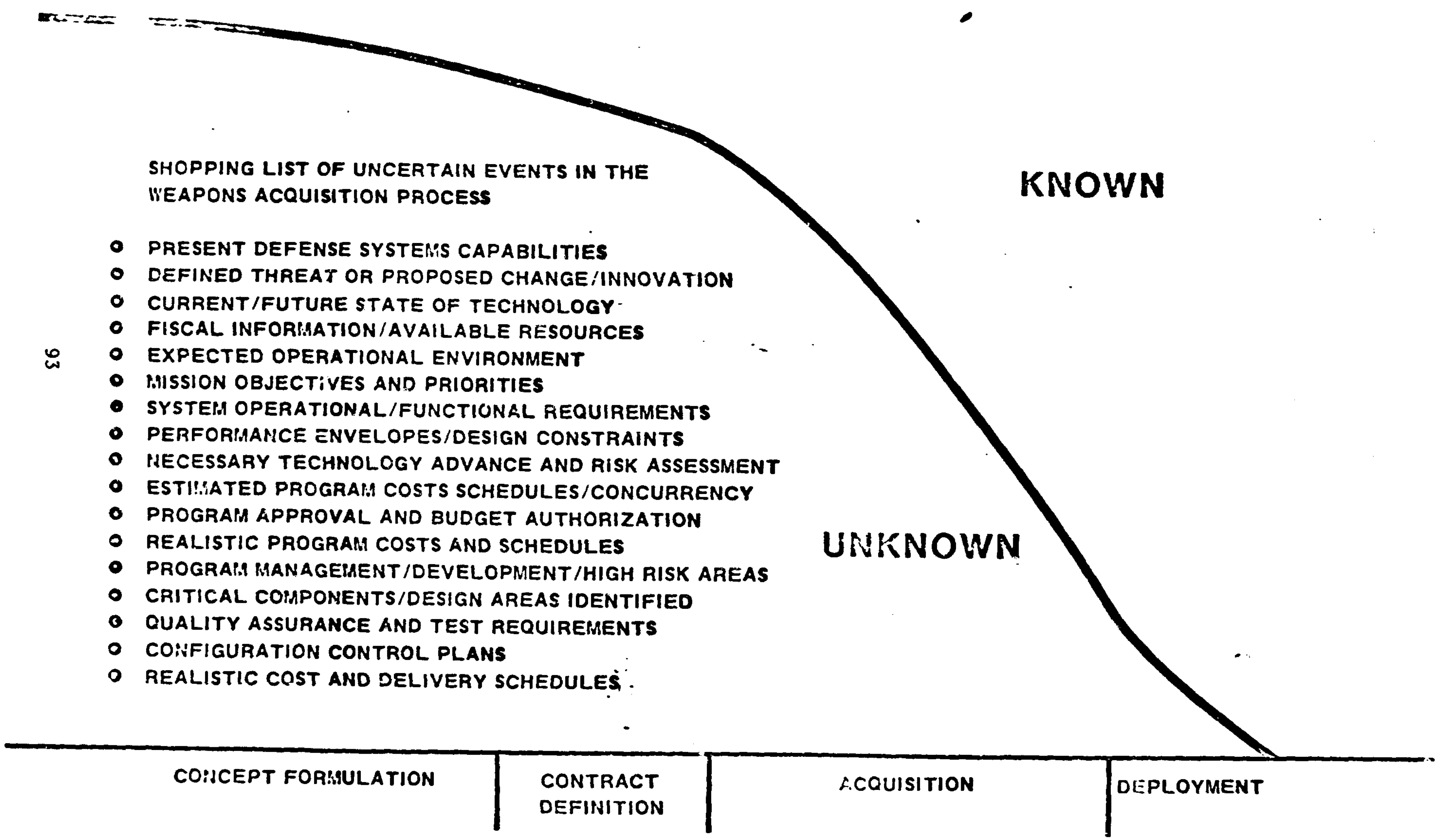
UNCERTAINTIES	TIME	COST	PERF.
POOR COST ESTIMATES	L	H	L
REQUIREMENTS CHANGES	M	M	H
DESIGN ERRORS	H	H	H
ANALYTIC ERRORS	H	H	H
ANALYTIC OVERSIGHTS	H	H	H
FABRICATION ERRORS	H	M	M
DEFECTIVE PARTS	H	L	M
DEFECTIVE RAW MATERIAL	H	L	H
CONTRACT INITIATION DELAYS	H	L	O
FUNDING DELAYS	H	M	O
BUDGET CUTS	H	H	L
PRIORITY CONFLICTS	H	O	O
PERSONNEL ACTIONS	H	L	M
FABRICATION DELAYS	H	L	O
DECISION DELAYS	H	L	O

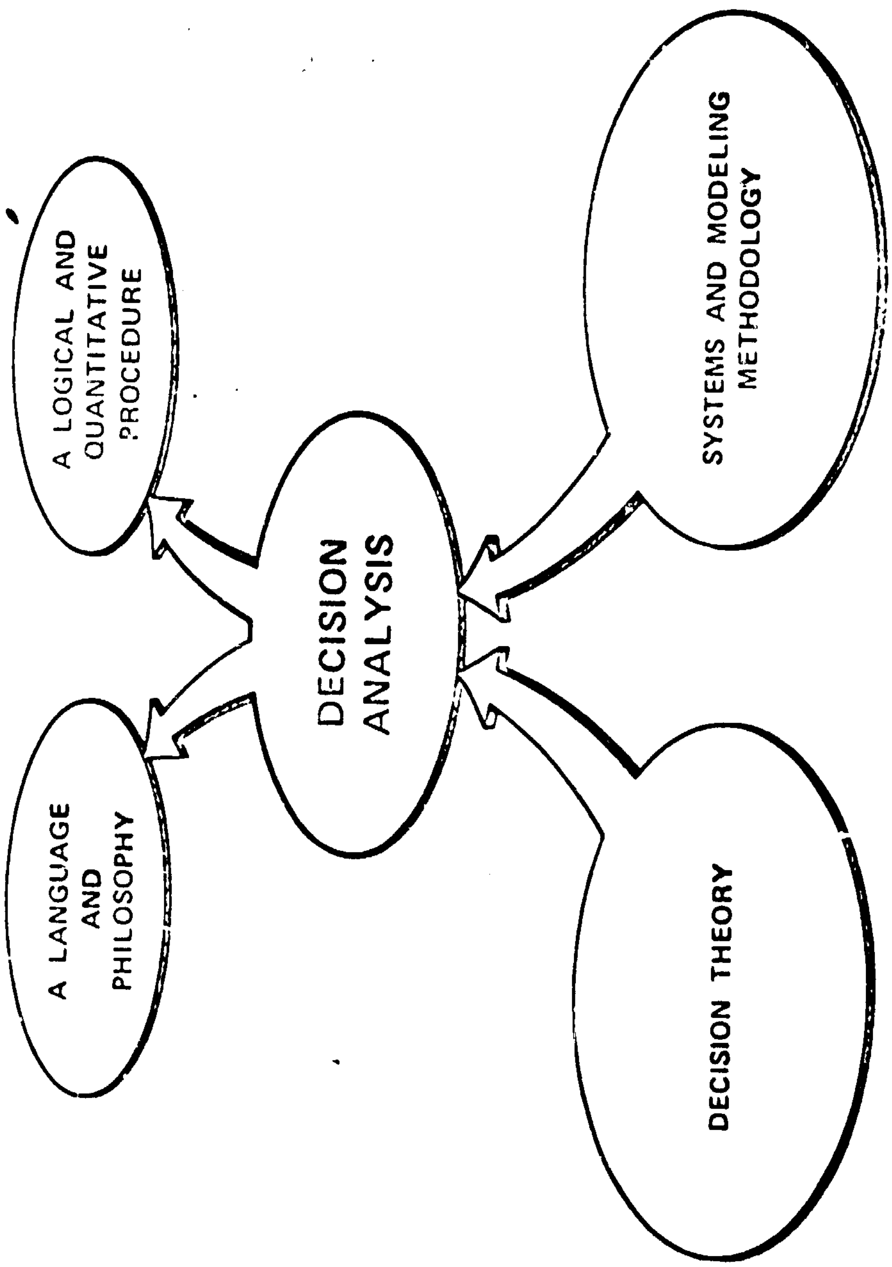
L - LOW PROBABILITY OF BEING AFFECTED IF PROBLEM OCCURS
M - MODERATE PROBABILITY OF BEING AFFECTED IF PROBLEM OCCURS
H - HIGH PROBABILITY OF BEING AFFECTED IF PROBLEM OCCURS
O - NO INTERACTION



Hearings before a subcommittee of the committee on Government Operations House of Representatives, June 19, 24, 25 and 27, 1969, subject: Government Procurement and Contracting (Part 9).

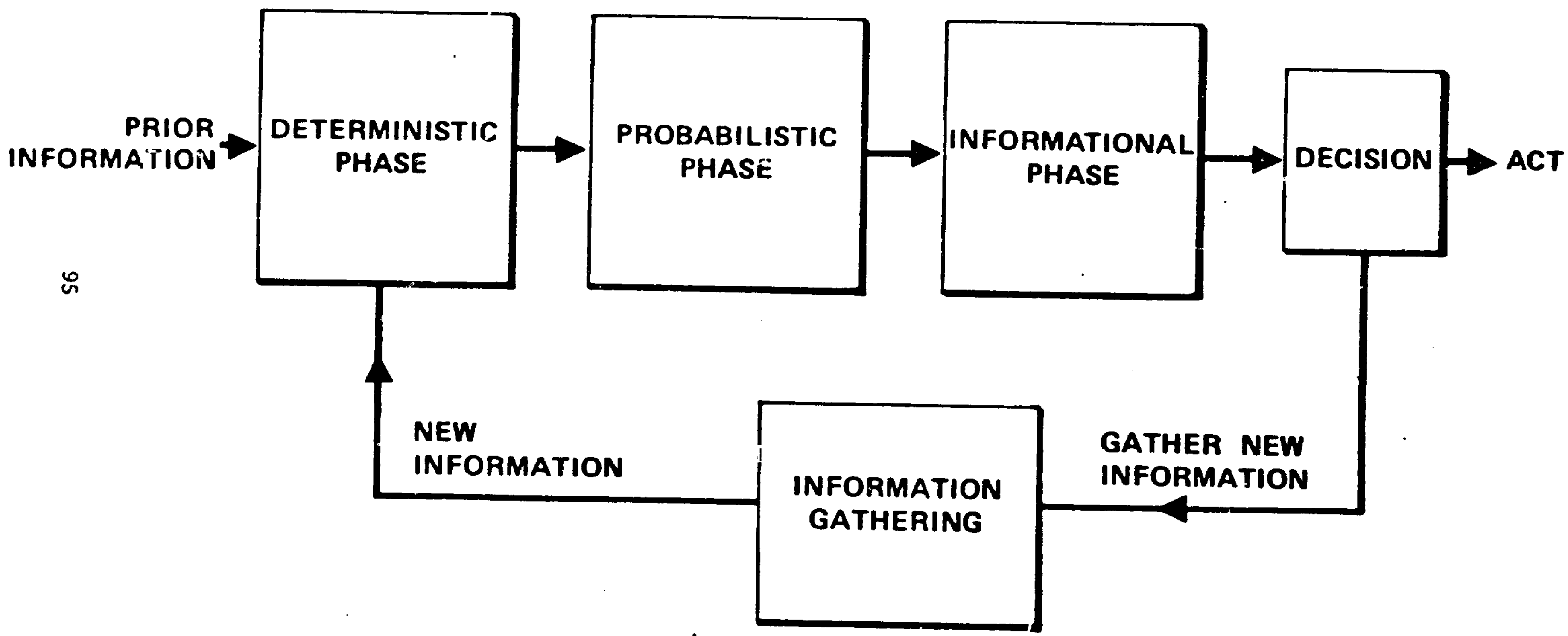
UNCERTAINTIES RESOLUTION





A LANGUAGE AND PHILOSOPHY
A LOGICAL AND QUANTITATIVE PROCEDURE
DECISION ANALYSIS
DECISION THEORY
SYSTEMS AND MODELING METHODOLOGY

THE DECISION ANALYSIS CYCLE

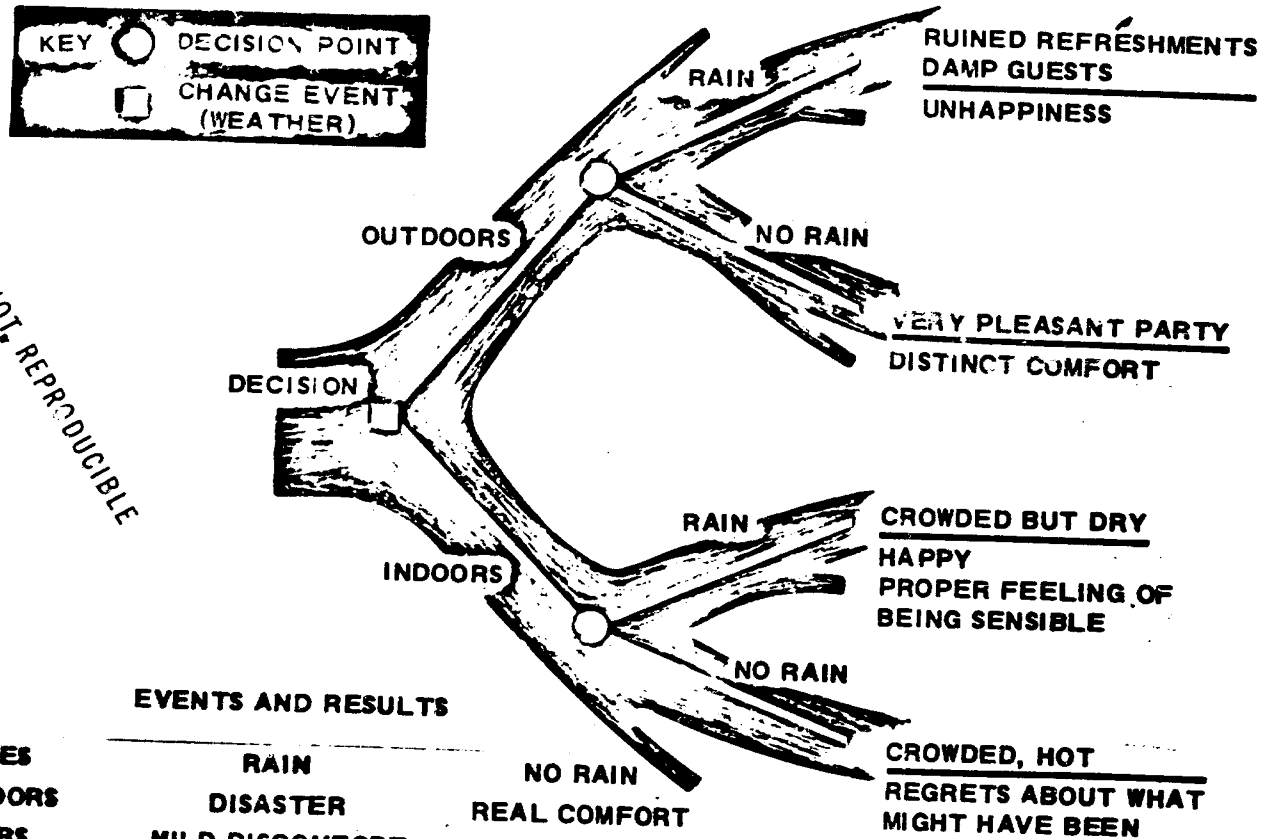


- GOOD OUTCOMES = DESIRABLE OUTCOMES
- GOOD DECISIONS = DECISIONS LOGICALLY CONSISTENT WITH INFORMATION & PREFERENCES

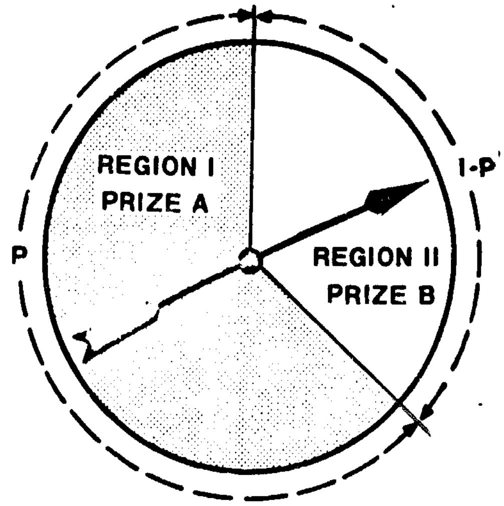
PURPOSE OF DECISION ANALYSIS

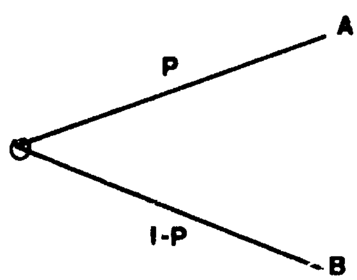
TO INCREASE THE LIKELIHOOD OF GOOD OUTCOMES BY MAKING GOOD DECISIONS

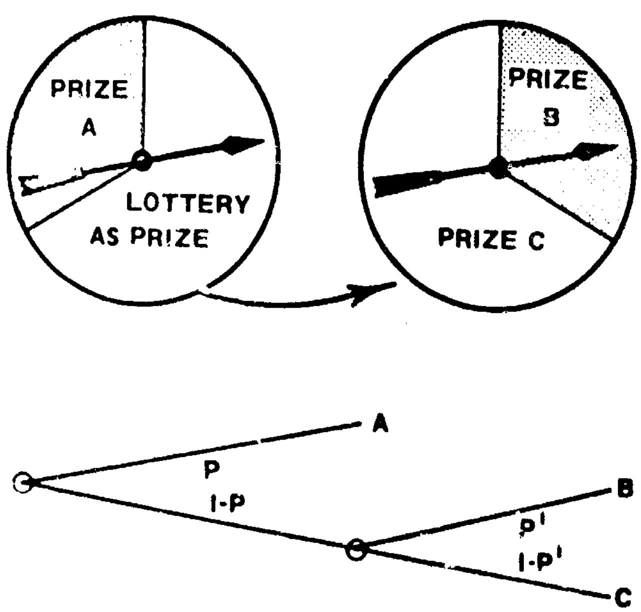
DECISION TREE FOR COCKTAIL PARTY



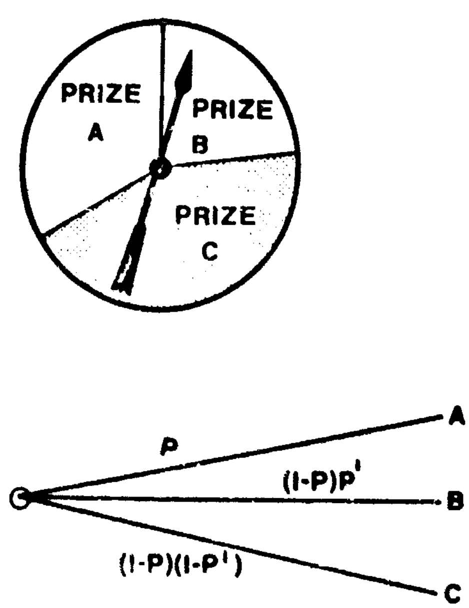
CHOICES	EVENTS AND RESULTS	
	RAIN	NO RAIN
OUTDOORS	DISASTER	REAL COMFORT
INDOORS	MILD DISCOMFORT, BUT HAPPY	MILD DISCOMFORT, BUT REGRETS





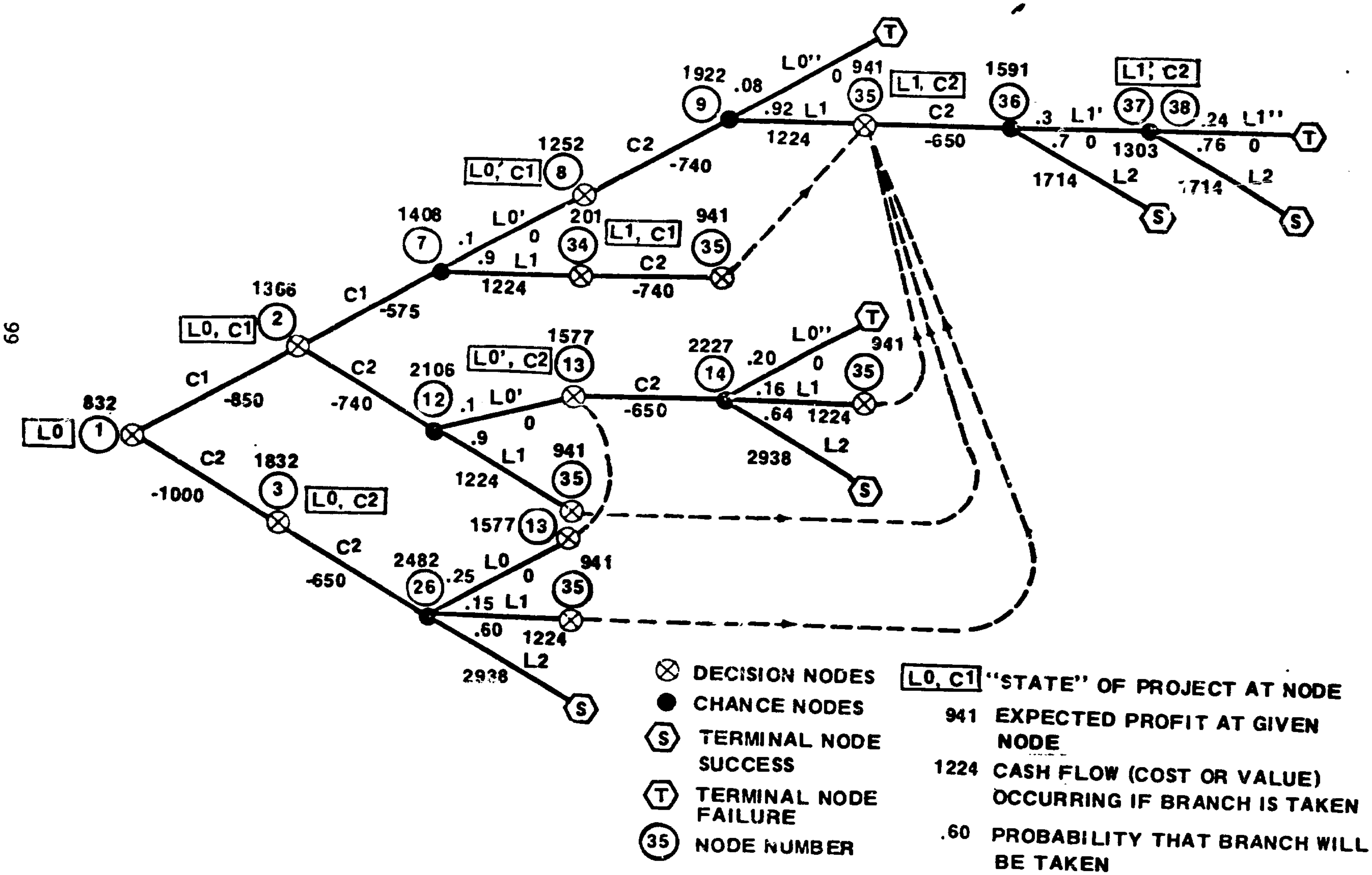


COMPOUND LOTTERY

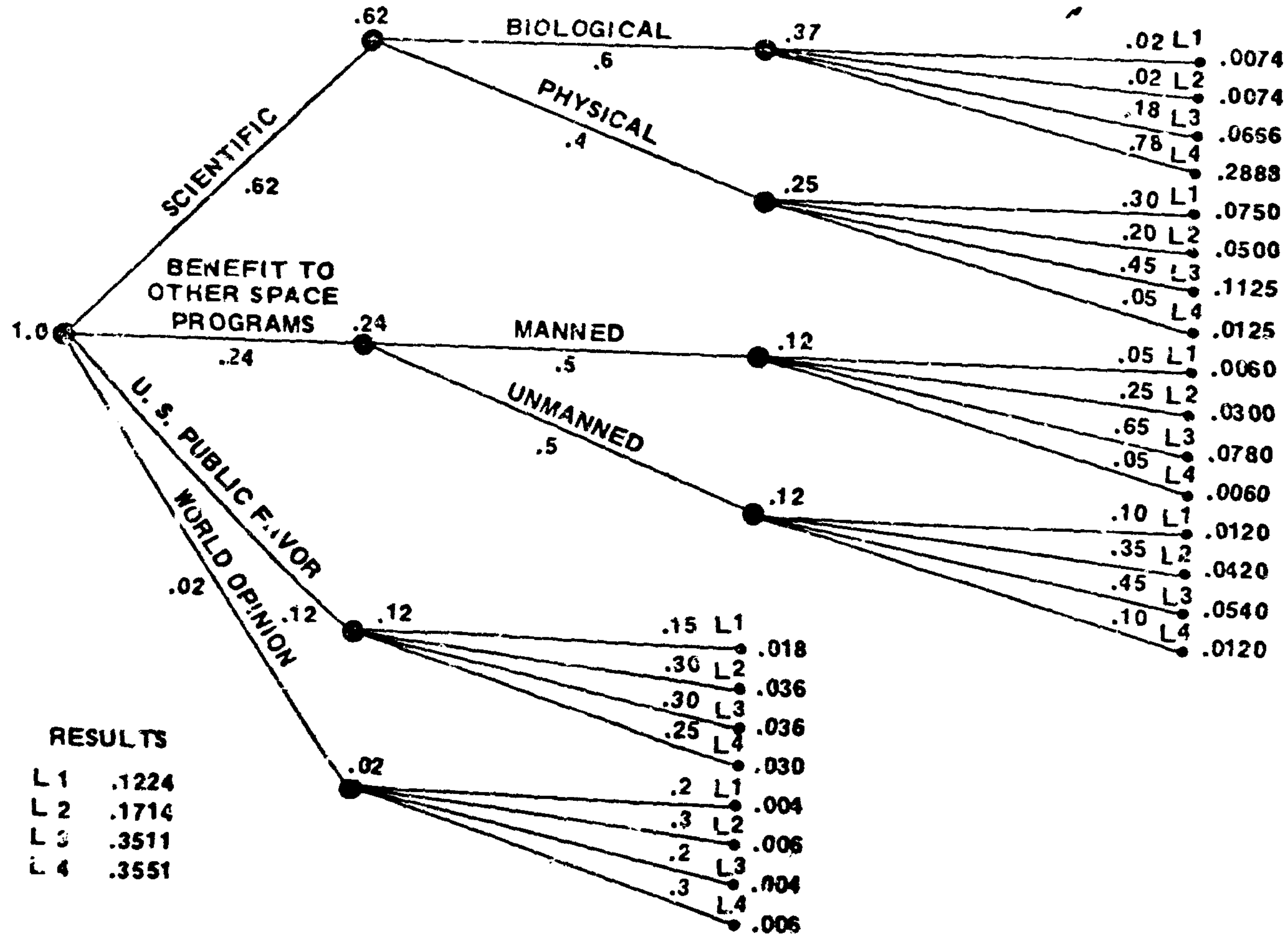


EQUIVALENT SIMPLE LOTTERY

EXAMPLE OF A DECISION TREE



THE VALUE TREE



HOW CAN RISK ANALYSIS BE USED

AS A TOOL FOR ANALYSIS

- WHAT UNCERTAINTIES EXIST ON PROJECT X
- WHAT ARE THE BENEFITS OF PROTOTYPE TESTING AND FALLBACK POSITIONS

AS A TOOL FOR DECISION

- WHICH PROJECT SHOULD BE SELECTED,
  A LOW COST/HI RISK PROJECT OR
  A HI COST/LOW RISK PROJECT

AS A TOOL FOR CONTROL

- WHAT IMPACT DOES A SCHEDULE SLIPPAGE IN A GIVEN TASK HAVE ON PROJECT COMPLETION

DECISION RISK ANALYSIS:

Problems In Practice

by
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INTRODUCTION

A decision is loosely defined as a choice between alternatives, that results in an allocation of resources - money, men, time, etc. There are good decisions - good in the sense that they were logically made. On the other hand, there are also good outcomes. The assumption is, of course, that a good decision will lead to a good outcome.

Decisions are made from the consideration of objective data classed as certainties, and objective and subjective data classed as uncertainties. The manager - using the word in its broadest sense - is constantly faced with the integration of uncertainties with certainties, to make his decision.

The manager is thus, by profession, a decision maker, and is constantly faced with the integration of certainties with uncertainties. However, this professional decision maker is very frank about his inability to explain and analyze his act of decision.

Decision Risk Analysis is a logical procedure for considering and assessing these factors that influence the decision. This approach makes use of the uncertainties, as well as certainties, in a decision model. Ronald Howard, in his paper "Decision Analysis - Applied Decision Theory," presented the Decision Risk Analysis (D.R.A.) process in the tabular form shown below:

TABLE I

1. Deterministic Phase.

    1. Define the decision
    2. Identify the Alternatives
    3. Assign values to outcomes
    4. Select state variables
    5. Establish relationship at state variables
    6. Specify time preference.

Analysis: a) Determine dominance to eliminate alternatives
b) Measure sensitivity to identify crucial state variances.

2. Probabilistic Phase.

    1. Encode Uncertainty on crucial state variables

Analysis: Develop profit lottery.

    2. Encode risk preference

Analysis: Select best alternative.

3. Post Mortem Phase.

Analysis: a) Determine value of eliminating
b) Develop most economical information gathering program

from: Howard, R. A., "Decision Analysis - Applied Decisions Theory"

G.I.G.O. GARBAGE IN GARBAGE OUT

The analysis of the D.R.A. procedure reveals that the key element of the approach is data. The success or failure of the procedure is dependent upon the data used.

To begin with, data are often difficult to obtain. They are not readily available, and thus have to be "dug up" and tailored for the D.R.A. In addition to the data being unavailable, they may be available but hard to get at. Possessors of data or the knowledge base to generate data are reluctant to produce data. They may be afraid to part with the data for fear that they will be later used as a standard or measuring stick to assess their own work performance.

Inaccuracies can also creep into data. For example, the data giver may adjust his figure for the probability of success of his project upward in order to insure its inauguration or continuance.

Therefore, unless unavailability, incompleteness, and inaccuracy of data are avoided, the result of a D.R.A. will be as noted in the title to this subsection.

JUDGEMENTS

Even when data can be made available, and will be complete, it will have to be based on the judgements of people. Now, there is nothing wrong with using judgements. The strength of the D.R.A. procedure is its ability to take judgements - subjective data, probabilistic data - and use them in an objective fashion, that will lead to a decision based on logic.

The problem with the use of judgemental data is whom to get it from, and how to get it. The question of whom to get the judgements from involves knowing who has the knowledge and background to be able to make the judgement. In many cases the judgement making ability will lie with a subordinate, and it will take tact and diplomacy to get around the subordinate's supervisor.

The question of how to get these judgements involves getting a person to commit himself to a number - to express his judgement as an objective piece of data. North and Spetzler discuss an interesting approach for transforming judgements into probability values. Using a forced choice approach, an individual's judgement or subjective values can be measured on a relative scale. This can then be transformed into a utility plot, based on the concepts taken form Utility Theory.

VALUE ASSIGNMENT

Associated with having the decision maker come up with his honest judgements related to probabilities of success or failure of an event, is the necessity to assign dollar values to the various outcomes indicated by a decision model. The approach in this case may have to be initiated by the highest decision making levels. A value system has to be established as a matter of top policy. For example, what is the cost of a lost life? In a California case, survivors of 5 men who died in a private airplane crash were awarded a total of 22 1/2 million dollars. Does this make the value of a life about 4 1/2 million dollars?

Another aspect of value assignment is the consideration of intangibles. For example, how is the ecological cost calculated and accounted for? The outcome may be an oil spill, and the costs of lost product, mop up, and court fine can be calculated. However, how is the ecological cost calculated? And how is the cost of a loss of customers due to a "bad press" calculated? It will be a guess, at best.

WHAT IF THE DATA ARE INCORRECT

Between unavailable and incomplete data, forced judgements and value assignments, there is a good chance that the data fed into the decision model will be inaccurate. At this point the decision maker is rescued by a technique called Sensitivity Analysis (S.A.). The S.A. technique allows the decision maker to vary the value of a data input and assess its influence on the decision model's outcome. The decision maker can then decide what influence an error in the value of data inputs will have on the outcome. He will be surprised at the number of data inputs that the model will be insensitive to. However, if the model

outcome is very sensitive to a specific input, this will serve to warn the decision maker that accuracy of data input is essential.

MODEL BUILDING

Another problem area in the practice of D.R.A. is the building of the model. By definition, the model is used to simulate the real world. This model is used because it contains fewer variables than does the real world, and, thereby, is easier to manipulate and control. However, the fewer variables in the model, the more inaccurate will be its simulation of the real world. But, as the number of variables increase, and the simulation approaches "reality" the model manipulation becomes exceedingly difficult.

Thus, the problem of model building is one of how many variables to use.

Theoretically, mathematical and statistical techniques, with the aid of a computer, can handle many variables at one time. The human mind, however, cannot handle more than 7 to 9 variables at a time. Once this barrier is breached the meaning of any analysis becomes distorted and unintelligible.

Invoking rules such as Pareto's Law,[1] Occam's (Okham's) Law[2] and Sensitivity Analysis, will aid in the determination of the number of variables to use in the decision model.

An example of the proper use of variables in decision models is the use of the mathematics and statistics of reliability engineering to determine the probability of success of a system as complicated as the space craft and missile systems.

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[1] Pareto's Law suggests that 15% of the total number of variables will account for 60% of the outcome, 25% of the total number of variables will account for 25% of the outcome, and 60% of the total number of variables will account for only 15% of the outcome.

[2] Occam's (Okham's) Law (Razor, Principle) states that in explaining things not known to exist, the number of entities (variables) should not be increased unnecessarily. Put another way, the simplest solution is the preferred solution.

It was initially thought that each individual component and part would have to be put into the reliability model in order to get at the probability of success of the system. As it turned out, not all component failures had a direct influence on the success of the mission, while other components and parts that comprised mechanical systems could be assumed to have a 100% chance of success. By these and other means the number of critical variables to be considered were drastically cut and the analysis became manageable.

OTHER AIDS TO DATA GATHERING AND MODEL BUILDING

One way of improving on data of the "uncertainties" variety is to make use of a group of experts. The Rand Corporation developed a group decision making technique called the Delphi Method. The concept underlying the Delphi approach is that many heads are better than one. In the Delphi approach, the experts are polled on their opinions, which they give in a quantified form. These opinions are then laid out to form a distribution. The value used by the poll taker for decision purposes is essentially the most recurring value (mode) in the distribution.

Another technique to aid the decision maker is the "In Favor of Analysis" (I.F.A.). The I.F.A. approach is especially helpful in treating the so-called irreducibles or intangibles--data difficult to transform into dollar amounts, or into probabilities. In the I.F.A. each variable is rated on a relative scale as being either favorable or not favorable in its effect on various alternative outcomes. This pattern of favorable and unfavorable influences can aid the decision maker in his selection of variables or outcomes.

A final word on aids to the decision maker concerns the use of precognition or intuition. There are people who have an uncanny ability to fly by the seat of their pants. They act on hunches or instinct, or what may more properly be called intuition. There seems to be something unscientific about the use of hunches--at least, so many decision makers believe. Yet, the more complex the decision process, the more incomplete is the support evidence, and, therefore, the more intuitive the decision _must_ become.

If there are people in an organization who have proven track records in the use of intuitively developed data, in making intuitive decisions, then accept their judgments on variable values and even their choice of outcomes to strive for. Do not attempt to have such people logically explain the reasons for their choice. Research by the author has shown a relationship between people with precognitive abilities and decisions producing good outcomes (profits).

CONCLUSION

The D.R.A. approach is not without its problems, especially in the gathering of the data, and the building of the model for the decision. However, model building problems in the D.R.A. area are the same ones as found with model building in other areas. Therefore, since models have been successful in other areas, it can be assumed that enough knowledge about model building can be acquired to have it be successful in D.R.A. also.

As to the data collection problem, here again the same admonition can be given. It may be difficult to gather the data, but the D.R.A. approach does present a logical plan to consider variables and outcomes. Experience with data collecting will improve the decision maker's ability to ferret out information, and thus improve on his decision making process. Initial models can be made of small, not-too-complex problems, and, as the model building and data gathering abilities improve, the applications can be to more complex situations.

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PYROTECHNIC HAZARD EVALUATION AND RISK CONCEPTS

by

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Pyrotechnic Hazard Evaluation and Risk Concepts

1. Risk Assessment:

Edgewood's program of pyrotechnic hazard evaluation developed the "worst case testing" philosophy as a result of the failure of TB 700-2 testing to properly assess, from a safety standpoint, hazards involved in transportation, manufacture, and storage of pyrotechnics.

The present concept in conducting a risk analysis is to determine for each undesired event the probability (p) of its occurrence and the severity (S) of the losses.

$$Risk^* = f(p,s)$$

Based on these factors the event is deemed safe/unsafe depending on the degree of risk resulting, in a high/low ranking.

Failure of this type approach is demonstrated in the transportation industry in that it is based on past accident history without consideration of the ever changing nature of equipment, cargo, environment, and emotional temperament of the personnel. Specifically, the degree of risk is based on assumptions, opinions, and intuitive feelings rather than actual data.

* National Transportation Safety Board
Report Number: NTSB-STS-71-1

2. Background:

The Edgewood Arsenal pyrotechnic hazards classification and evaluation program is designed to evaluate materials to current criteria as well as determine if more meaningful criteria could be developed.

Based on the rationale that: (1) pyrotechnic hazards could be evaluated through application of normal and abnormal stimuli, (2) pyrotechnic hazard evaluation and explosive classification standards should consider the environmental envelope.

This activity conducted testing on a selected group of pyrotechnic granular compositions and end items to establish the hazard classification appropriate to transportation, handling, and storage as required by U. S. Army Technical Bulletin 700-2.

These tests consisted of:

--- Ignition and unconfined burning test

--- Standard detonation test

--- Thermal stability test

--- Card Gap test

--- Impact Sensitivity test

The ignition and unconfined burning test, performed to determine the probability of the test material propagating burning or deflagration into detonation, is evaluated by determining whether a detonation took place and by recording the burning time in seconds. However, the pyrotechnic tested

simply burned, as designed.

The standard detonation test, performed to determine the probability of the test material detonating in free air, evidences detonation by mushrooming of the lead cylinder, but, no such reaction was noted for any sample.

The thermal stability test, conducted to determine the probability of the test material decomposing under application of external heat, might lead to a DOT forbidden classification should explosion, marked decomposition, or burning occur. However, the results were negative for all samples.

The card gap test, performed to determine the sensitivity of the test material to sympathetic detonation from an explosive shock wave, confirms detonation of the sample material if a clean hole is punched in the witness plate. None of the pyrotechnic card gap tests resulted in evidence of detonation -- in fact, they indicated that the pyrotechnic actually attenuated the pentolite reaction rather than contributing to it.

The final TB 700-2 test performed was the impact sensitivity test utilized to determine the probability of the test material decomposing or detonating as a result of mechanical shock. Conducted with the Standard Bureau of Explosives apparatus, using an 8 pound weight impacting on a 10 milligram sample at drop heights of up to 10 inches, the test is evaluated by observing noise, smoke and/or flame and decomposition. While the validity of impact

sensitivity testing is highly suspect because the evaluation criteria is imprecise (human error and small sample size) this was the only test in which samples exhibited a positive response.

The benefits derived from a classification system such as increased safety are only as substantial as the validity of the established criteria. Specifically, all of the TB 700-2 tests were obviously designed for materials generally classified as mass detonating explosives. Pyrotechnics, which are basically designed to burn under various conditions at various rates, certainly cannot be expected to react to the stimuli specified by TB 700-2 in a manner providing conclusive data on a "go-no-go" test.

3. Worst case testing concepts:

The objective of any safety analysis is to establish that a process is safe rather than unsafe; and this is the primary objective of worst case testing.

The rationale for worst case testing is to obtain rough order of magnitude of potential severity. Therefore, compensating controls for "worst case" will apply to reactions of lesser severity.

From a program point of view, it establishes whether there is a requirement for further testing to determine under actual conditions the existence of a hazard potential or whether further testing is not required because there is only a minute possibility of a significant hazard potential. Consequently,

worst case testing is designed to maximize test applicability to hazard analysis, while minimizing the number of required tests.

The hazard potential is related to the probabilities of initiation, communication, and transition (ICT); thus, the actual test performed may be intended to measure any one of the elements of the ICT sequence.

Although this technique has been applied only to hazard studies in which ICT provides an appropriate framework, it also has general applications outside of the pyrotechnics and explosive industry.

The consistency matrix shows the variety of interpretations available from a worst case test series.

4. Worst Case Simulations:

In order to recommend modification of existing standards, Edgewood conducted normal and "worst case" operational simulation to determine the hazards involved in the manufacturing and transportation environments.

Based on the rationale that pyrotechnic dust suspension in the manufacturing environment presents initiation, communication and transition hazards, tests utilizing a modified Harthmann apparatus for laboratory evaluation of the explosive characteristics of pyrotechnic dusts and investigations in partly open chambers or galleries of 75 cubic inches to 512 cubic feet were conducted.

These tests resulted in:

--- Determination and correlation of ignition (explosibility) characteristics with pyrotechnic dusts

--- Development of order of magnitude and scale requirements for "run-up" potentials in processing plants

--- Attainment of a "sonic reaction front" in tests

--- Identification of follow-on test programs

In an effort to establish compensating controls for potential hazards in the manufacturing/processing environment, Edgewood considered worst case conditions to determine rough order of magnitude of potential severity.

Essentially, the approach for this "worst case" testing was to determine a pyrotechnic's reaction when confined to the maximum credible degree under manufacturing operations (reaming, mixing, and pressing) and, to determine nature and degree of resultant fragmentation/fire/overpressure hazards.

The overall "worst case" testing project developed and identified needed "ICT" parameters; established that detonation/fragmentation hazards did not exist in any operation tested and identified the major potential hazards as fire and low grade explosions.

The data obtained from this initial probe of manufacturing/processing environment has already resulted in more meaningful hazards classification/

protection criteria, increased operational flexibility, and new technological and safety concepts.

To represent a maximum probable situation in the transportation environment, Edgewood utilized 1/50 scale model truck trailers constructed for confinement tests on nine 48 unit cases of XM-9 C/S canisters.

The results of the two tests were significantly different. In the 48 unit trailer test, case to case propagation was attenuated and fire suppression was accomplished by the confined environment of the trailer simulator. However, in the 500 unit trailer test, the single case was totally consumed and rupture of simulator at 12.5 PSI allowed total burning of all C/S and trailer simulator.

These tests demonstrated the importance of packaging material and design, as well as revealing the need for new concepts such as the requirement for on-board fire suppressor/attenuator systems. In essence, this philosophy affords a means of determining the hazards and risks involved in the transportation, storage, and handling of hazardous materials based on actual data rather than assumptions, formula, opinions, or intuitive feelings.

In summary, the Edgewood Hazards Evaluation Program has accomplished its job-evaluation to current criteria. Anomalies have been identified in existing criteria, and recommendations made for more meaningful standards.

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THE ENVIRONMENTAL RISK ARISING FROM THE BULK STORAGE OF DANGEROUS CHEMICALS

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The environmental risk arising from the bulk storage of dangerous chemicals

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Summary

In this paper considerations are given regarding questions as:

"Is there a danger for residental area's from the bulk storage of dangerous chemicals"

and "If so what kind of danger is this and how great is the danger?"

In the first section a theoretical analysis of danger and the factors involved are given.

This analysis is in a second part applied to the bulk storage of dangerous chemicals.

A method for an approach to tackle the problem of storage of dangerous liquids and distance from residential area's is given.

In the conclusions a recommendation for international exchange of information is included.

The environmental risk arising from the bulk storage of dangerous chemicals.

Introduction

For several years the chemical industry has been growing at a fast rate and this consequently bears its influence on the streams of raw-materials intermediates and end-products. These materials are being stored and shipped in increasing units and quantities.

A considerable number of the chemical substances used, produced and/or stored in the chemical industry are classified as dangerous substances. This means, that through their properties they have the capability of inflicting harm upon their environment.

This situation being so one has to try to solve questions as:

1. Is there a danger for the general population from the storage of dangerous materials?
2. If so, what kind of danger is this and
3. how great is this danger?

In this paper consideration will only be given to the dangers resulting from a large incident at the storage of dangerous materials or during shipping of dangerous materials. (The influence of continuous pollution of the air from venting or similar operations therefore, will not be taken into consideration.)

Theoretical Analysis

In order to be able to answer the above-mentioned questions one has to determine which factors are involved.

Any danger now, is a combination of two essential items:

1. the hazard; that is the potential capability to inflict harm.
2. the risk; that is the probability, that harm is being realised.

The magnitude of the hazard together with the magnitude of the risk gives the magnitude of the danger.

A combination of two systems (a) and (b) will now be considered, whereby system (a) presents a danger for system (b).

1. The hazard in this situation depends on:
   1.1 The properties of the constituents of system (a)
   1.2 The size of system (a)
   1.3 The distance between system (a) and system (b)
   1.4 The possible presence of some kind of protection.

2. The risk in this system depends on:
   2.1 The type of system (a)
   2.2 Internal factors of the system (a)
   2.3 External factors influencing system (a)
   2.4 Independant factors with regard to system (a) and system (b).

Some comments on the factors, which determine the hazard.

1.1 The properties of the constituents of system (a)

In general system (b) can be harmed by system (a) in three ways:

- 1.1.1. -

1.1.1. Transfer of kinetic energy; this is the case if system (a) or parts belonging to system (a) collide with system (b)

1.1.2. Sudden release of potential energy; this is the case when a fire or an explosion is generated;

1.1.3. Other ways of generating an impact; eruption of toxic gas, harmful radiation, germs.

1.2 The size of system (a)

It will be apparent, that the size of system (a) is one of the most important factors, which determine the possibility to influence system (b).
Not only the size, but also the length of the period, during which system (a) exhibits its harmful effect, is very important; e.g. the amount to which and the time during which people are exposed will determine the severity of the effects of toxic gases; the same amount of energy released over a very short period of time (detonation) is much more harmful than that same amount released over a longer period (deflagration).
In order to estimate the hazard of a system, one has to determine the "maximum credible accident".
The "maximum credible accident" is the largest accident, which one can imagine to occur under any conceivable circumstance.

1.3 The distance between system (a) and system (b)

It is evident, that the greater the distance between system (a) and system (b) the less the influence.
The factor of distance is a very important parameter as for instance in the case of the spreading of toxic gases, roughly speaking the concentration is inversely proportional to the square of the distance.
So if the distance is doubled, the concentration will be reduced approximately by a factor of four.
At that distance, where the greatest change in system (a) has no longer ill effects on system (b), system (b) is in absolute safety. The danger is then nil.
This distance in practical cases often can't be realised and therefore a so-called "safe distance" should be determined. The "safe distance" in this regard is that distance at which system (a) presents an acceptable calculated danger for system (b). (The determination of the safe distance is fundamentally a policy decision!)

1.4 The possible presence of some kind of protection

Regarding protection or protective systems one can think of various possibilities (which need not be equivalent arrangements).
Three different types can be distinguished:

a natural system (e.g. hills, rivers)

a technical installation (tankwall, automatic shutdown equipment)

an organisational system (stand-by rescue/fire brigade)

- Remark -

Remark: It would be desirable to develop a way to compare these types of systems with the protection gained by distance. In that case, one could correlate the protection gained by a system with the protection gained by distance only.

Some comments regarding the factors which determine the risk.

2.1 The type of system (a)

The probability of system (b) being harmfully influenced is directly dependant upon the probability of the occurence of a large incident.
This again depends on the character of system (a).
There is a great difference between storage, transport and processing. In any of these systems the way of handling and the frequency of handling is different from the others.
In general it is the amount of handling, that determines the risk.

2.2 Internal factors of system (a)

Some factors which undoubtedly have a great influence on the chance of an accident occurring are:
the choice of materials of construction
the state of maintenance
the policy of top-management
the lay-out of the plant
the level and number of employees etc.

2.3 External factors influencing system (a)

Some examples are:

- regulations -

regulations from authorities

amount and thoroughness
of inspection from authorities

actions of third parties;

2.4 Independant factors with regard to system (a) and system (b)

The most important independant factor is the type of weather.

This can be extremely important in connection with the development of explosive gas-mixtures and the diffusion of toxic gases.

Application of the theoretical analysis for the bulkstorage of dangerous materials

The dangers related to the presence of harmful materials arise from the storage and the transport of these products. Transport occurs by ship, road-tanker, rail or pipeline.

The factors, which determine the danger were given in 1.1 to 1.4 inclusive and 2.1 to 2.4 inclusive.

The shipment of a dangerous product (either by water or by land) can be considered to be a mobile storage system. This implies that the hazard will be the same as in the case of a fixed storage system, but the risk is different.

- The -

The hazard

The hazard is given by the factors 1.1 to 1.4 inclusive

Factor 1.1: The properties of the constituents.

This in fact means the properties of the materials, which are stored.

In a storage-system transfer of kinetic energy can be excluded; possible ways of affecting the environment are however:

fire, explosion, eruption of toxic gases and contamination of the soil or watersystems with toxic products.

Factor 1.2: The size.

In the evaluations the influence of the maximum credible accidents have to be considered. So these maximum credible accidents must be selected.

The bulkstorage of dangerous materials can be:

- storage of solids
- storage of liquids
- storage of gases (or liquefied gases)

The accidents, which have the widest direct influence are those accidents, which occur with large quantities and which result in the generation of toxic vapours.

For Holland the maximum credible accidents are probably:

	Land-storage	Transport
Solids	Decomposition of ammonium-nitrate fertilizer 3000 tons	Sea-transport decomposition of 3000 tons.
Liquids	Release of 5000 m3 Acrylonitrile in a tank-pit of 1600 m2	Outflow of 1000 m3 acrylonitrile in the river
Gases	Release of LPG followed by detonation and fire	Release of 50 tons of liquid chlorine (rail-tankcar) or release of 2000 tons of liquid ammonia into the river.

For liquids the complete release of the contents of a storage-tank is taken. Because of the regulations in the Rotterdam port-area this results in 5000 m3 in a tankpit of 1600 m2.
On the same grounds the decomposition of 3000 tons fertilizer is chosen.
In the case of gases the complete release of a chlorine- or ammonia-tank seems inconceivable. Therefore the release of LPG is chosen.
In the case of the transport-accidents, the quantities chosen are the largest quantities, transported regularly in one unit.

Factor 1.3: The distance

A large fire even if some tanks are involved, has a direct influence on the environment which remains restricted to an area within 500 m of the fire.

A large explosion (detonation) exhibits its influence at a much wider area. From experience however it can be said that generally serious damage does not occur at a distance larger than ± 1500 m.

In agreement with this experience are some international regulations which prescribe a distance of 1000 - 1600 m between residential area's and the storage of units of 100 tons of ammunition of the most dangerous type.

Release of toxic gases or vapours can result in dangerous situations at comparatively large distances.
One has to think in terms of km's.
What actually will be the situation depends mainly on the quantity released, the time-period during which the emission takes place and the atmospheric stability.

Factor 1.4: <u>The possible presence of some kind of protection.</u>

Through installation of technical provisions one may be able to restrict the influence of a possible incident. Storage of explosive chemicals can be surrounded by concrete walls and spillages of liquids producing toxic vapours may be covered with foam. Absorption-towers may provide protection against spillage of toxic gases.
All these types of protection will shorten the "safe distance".

- The -

The more reliable the protection the smaller the "safe distance" can be, as the "safe distance" is defined as that distance, at which one stands an evaluated and accepted amount of danger.
As much as possible quantification of the danger should be carried out.
For instance, if it can be assured that a spillage of acrylonitrile will be covered with foam, within half an hour the "safe distance" can be based on the EEL-value for the general population for ½ hour. (see Emergency Exposure Limit)

<u>What hazard is to be expected at different distances</u>?

As in Holland in the Rotterdam port-area large quantities of acrylonitrile are handled, this question has been examined for the maximum credible accident at land-storage, which means a tank-pit of 1600 m2 covered with acrylonitrile.
The effects will depend mainly on the weather conditions.
For sake of simplicity a division into three groupings will be taken:
Unstable-, neutral- and stable atmospheric conditions.
(In terms of Pasquill classification: A-B, C-D and E-F)
As the vapour pressure depends on the temperature a rough separation between summer- and winterconditions is necessary.
For our country this means, that the vapour pressure in wintertime is approximately 0,45 times the vapour pressure in summertime.

- For -

For the "maximum credible accident" of 1600 m2 of acrylonitrile in a tankpit the following sources of emission were calculated for summer-conditions:

Unstable atmospheric condition: 5.9 kg/m2h

Neutral atmospheric condition : 10.2 kg/m2h

Stable atmospheric condition : 7.2 kg/m2h.

In case of winter-time the sources of emission are calculated from these figures by multiplying with the factor 0.45.
For the values of concentrations to be expected at various distances is calculated: (ref. 1.)

Acrylonitrile concentration in mg/m3.

Atmosph. condition / Distance	Unstable		Neutral		Stable	
	summer	winter	summer	winter	summer	winter
100 m	2500	1100	4500	2200	30.000	13.000
300 m	250	100	900	400	5.000	2.250
500 m	100	45	300	135	2.000	900
1000 m	50	20	100	45	650	300
2500 m	15	7	20	8	175	80
5000 m	2	1	1	<1	65	30

In case of water-transport the assumed maximum credible accident was the outflow of approx. 1000 tons of acrylonitrile into the harbour.
At such an incident the liquid will spread itself very rapidly over the water-surface.
The width of the river in the Rotterdam port is ± 500 m. So

- if -

if one assumes a final layer thickness of 1 mm, the liquid will spread over a length of 2 km. In practice this will not be so, as evaporation and dissolution will take place. The spreading of this sort of liquid however is much quicker than the evaporation and dissolution.

From comparison with gasoline one would expect a spreading over a width of 500 m and a length of 1000 m in 10-20 minutes. (Ref. 2)

If no evaporation and dissolution would have happened, the layer-thickness would have been 2 mm. In the majority of weather-conditions the combined evaporation and dissolution in a period up to 20 minutes would not account for a reduction of layer-thickness of 1 mm (being ± 500 tons).

Therefore one has to expect a spreading over the full width of the river over a length of at least 1 km., with a film 1 mm thick.

The evaporation is estimated at 2,2 kg/m2h. This would mean, ± 20 tons/min. om the estimated surface.

The evaporation rate will be relatively lowered in case of such a large surface. Also the influence of the wind speed and the temperature is very large. Another factor is the dissolution in water. All these factors together determine the time-period, during which the dangerous situation will exist.

From these considerations, however, one can say that this situation will be present over a time-period ranging from half an hour to two hours.

A complicating factor is the tide. This can mean that the evaporating surface moves up or down the river.

To predict downwind vapour-concentrations at various distances

- is -

is very difficult indeed. The large surface implies a strong source of emission. The larger the surface the smaller the time-period during which this situation will exist.
It seems probable however that one has to reckon with dangerous concentrations at distances up to several km's.

Safe distance: What will be in case of these "maximum credible accidents" the "safe distance"?
As already mentioned, this is in fact a policy-decision, as one has to answer the question:

"What danger is acceptable at what frequency?"

It seems logical to use for the permissible dose the concept Emergency Exposure Limit. This EEL value is that concentration, that the general population in emergency conditions is supposed to be able to withstand for a certain time-period without an irreversible negative effect. EEL-values are given usually for half an hour or 1 hour.
In our country an EEL of 90 mg/m3 is accepted for exposure during a half hour to acrylonitrile.
The question remains: How often can we accept such a situation?
This question has to be answered by the authorities.

The Risk

Only regarding land-storage tanks some information appeared to be available in Holland on the occurence of large incidents. Therefore quantification of the risk is only attempted for this type of accident.
The factors, which determine the risk have been given in 2.1 to 2.4 inclusive.

- Except -

Except for factor 2.4 it is almost impossible to calculate the influence of the individual factors. Therefore some idea of the order of frequency of the incidence (possibility) of these large accidents must be collected from the history of incidents.

From a survey on large incidents with storage tanks in the Rotterdam industrial area it appeared that from 1945 to 1970 there has been one serious incident per ± 3000 tank-years. (a total of 11 incidents) A tank-year is a tank, that has been in use for a year.

This survey included all sorts of tanks.

Because of the factors 2.2 and 2.3 the storage of dangerous liquids is regarded with more care than that of other liquids. It is therefore safe to say that the chance of a large incident occuring at the storage of dangerous liquids in the Rotterdam-area is smaller than once per 3000 tank-years.

The influence of the weather-conditions.

The risk for population situated a certain distance from a storage of dangerous liquids also depends on the atmospheric stability at the time of the incident occuring. The influence has been shown in the table on page 11.

Now the question remains: "how often are unstable-, neutral- or stable atmospheric conditions occuring?"

From a survey of the Dutch Royal Institute of Meteorology it appears, that for the Rotterdam Area the situation is:

Unstable atmospheric conditions: 12,5%

Neutral atmospheric conditions : 65 %

Stable atmospheric conditions : 22,5%

- Determination -

Determination of the danger and the "safe distance" for a residential area.

Through combination of the figures from the table on page 11 and the percentages mentioned above, one is able to estimate the probability for various concentrations at various distances.

This leads to the curves given in figure 1.

As EEL-value for half an hour 90 mg/m3 was quoted.

From figure 1 it is seen that at a distance of 2500 m there is a probability of 20% of exceeding this value (at a distance of 1000 m this probability exceeds 50%.)

The chances of the maximum credible accident occuring at the storage were once in 3000 tank-years or less.

If it is assumed that residential area's are situated in half of the wind-directions around the storage, the chances are once in 6000 tank-years.

Now roughly spoken storage-tanks are just as often full as empty, so the chances for an accident with a full tank are once in 12.000 tank-years

At a distance of 2500 m the probability of exceeding the EEL-value at a residential area are 20%.

So this means once in 60.000 tank-years.

If now the <u>accepted risk</u> is fixed at once in 10.000 years, this means that a storage of 6 large tanks is acceptable in a situation where residential area's are at a distance of 2500 m from the bulk storage.

From the above given reasoning it will be clear, that this is only an attempt to approach the order of magnitude.

- As -

As dangerous liquids are treated with much care and stringent conditions are maintained for the technical provisions, the above mentioned number of 6 tanks can as well be 12 or 18.

As sufficient statistical information on incidents with bulk storage of dangerous liquids is lacking, the inaccuracy is evident.

The same applies for the risk from other "maximum credible accidents". We are still trying to collect information for our country on the frequency of accidents. The same approach however is in principle possible for any accident. For water-transport one has probably to work with "ship-movements" instead of tank-years.

A "ship-movement" is a ship moving from one location in the port-area to another location.

Conclusions and Recommendations.

1. An approach is given for the estimation of risk for residential area's because of bulk storage of dangerous liquids.
2. As sufficient information for statistical calculations are lacking, only the order of magnitude can be indicated.
3. To improve the accuracy of this method it will be necessary to collect the information on large incidents on a world wide basis.

The problem of hazard evaluation in connection with dangerous chemicals is an international problem.

Dangerous chemicals are shipped from one country to another.

Therefore agreement on criteria for these hazards is needed.

The collection of information on the hazards of dangerous

- chemicals -

chemicals is a rather slow operation. Much has to be gained from experience.

It is like the fitting of a jig-saw puzzle.

As other countries may have in their possesion several pieces of the puzzle, international exchange of information is highly desirable.

This leads to the following

Recommendations for joint efforts:

1. that a hazard classification system be developed with mutual agreement on criteria; as a basis the tentative guide of the National Academy of Science can be taken; further implementations of the physical properties seems desirable;
2. that each party assembles an inventory of known experimental work at larger scales and sends this information to the other party;
3. that proposed experimental programmes be sent for comments to the other party;
4. that communication be established between working groups dealing with the determination of LEL-values for relevant chemicals; proposed LEL-values together with the information on which the figures are based should be exchanged for comments;
5. that for coordination a liaison-group be formed which will meet once in two years and which provide on either side an address for contact.

Ref. 1: Pamela M. Bryant:

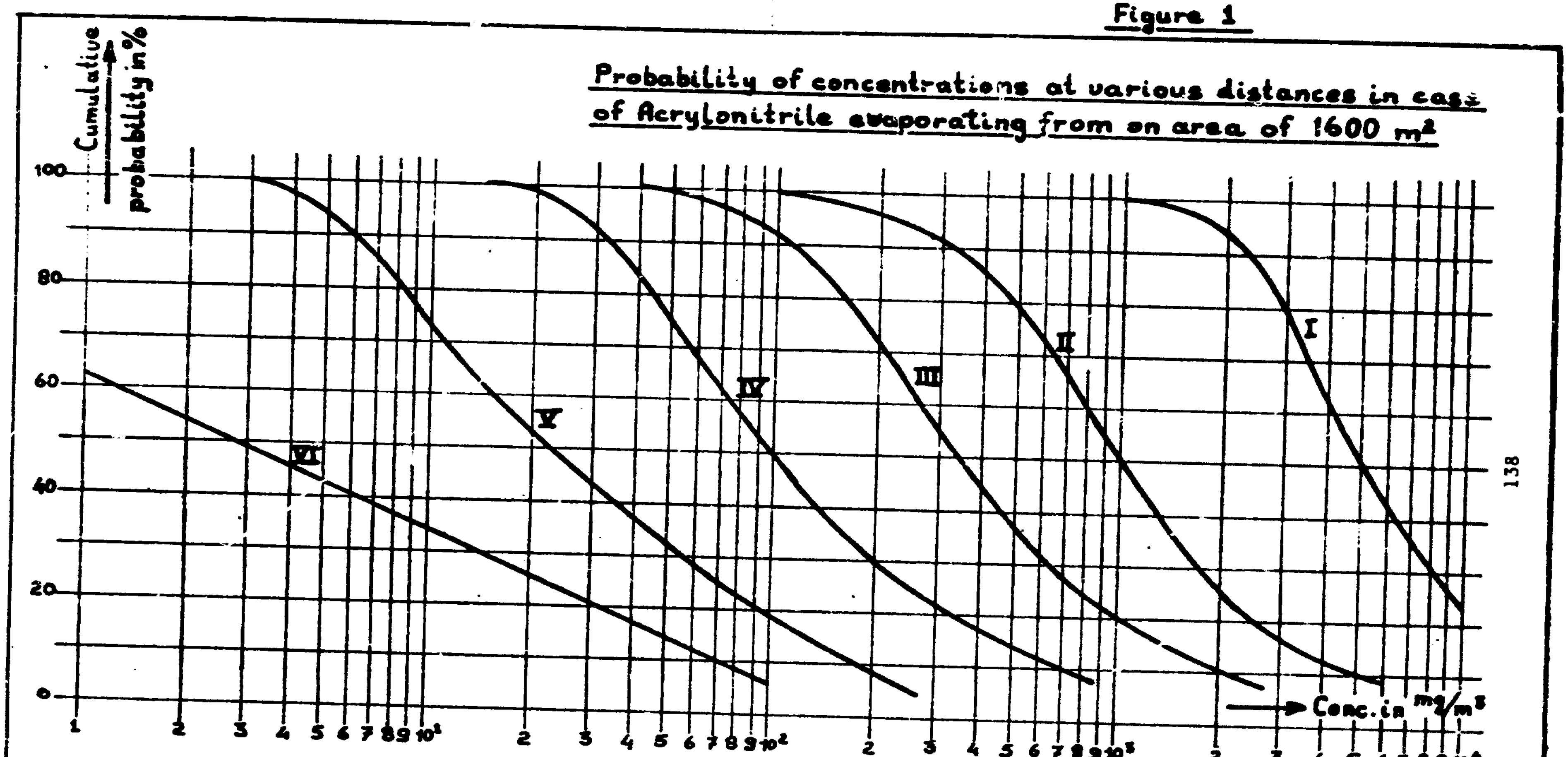
Methods of estimation of the dispersion of windborne material and data to assist in their application.
United Kingdom Atomic Energy Authority 1964

Ref. 2: P.C. Blokker:

Spreading and evaporation of petroleum products on water. 4th International Harbour Conference Antwerpen 22-27 June 1964

Figure 1

Probability of concentrations at various distances in case of Acrylonitrile evaporating from an area of 1600 m^2



I = 100 m
II = 300 m
III = 500 m
IV = 1000 m
V = 2500 m
VI = 5000 m

Wijziging	Stuk-No.	Datum	Zr. tek No	Aantal	Stuk-No.	Benaming	Materiaal	Afmetingen

Grafiek betr. verdamping Acrylnitril

Schaal:

ARBEIDSINSPECTIE

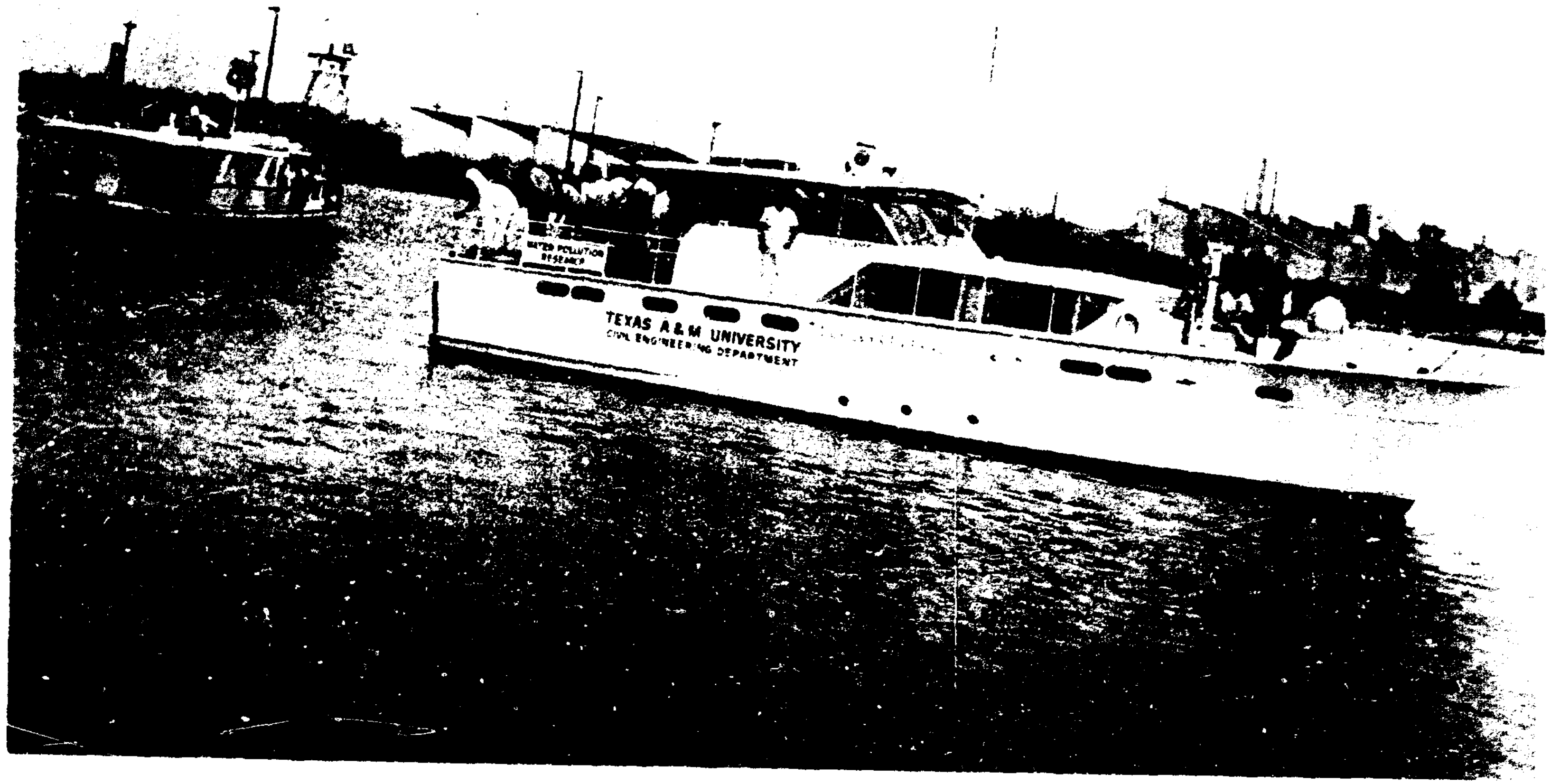
Get.: AVan... Gecalq. AVV

Gez.: Datum: 8/4/71

Formaat A4

No. 15402

UDC 628.512.4:53.08



INSPECTION TOUR OF SHIP CANAL WAS MADE ON THREE VESSELS PROVIDED BY TEXAS A&M UNIVERSITY
(Two Shown During Bottom Sampling Operation)

THE GEOGRAPHY AND ECOLOGY OF THE
HOUSTON SHIP CHANNEL - GALVESTON BAY SYSTEM

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September 1971

THE GEOGRAPHY AND ECOLOGY OF THE HOUSTON SHIP CHANNEL - GALVESTON BAY SYSTEM

Galveston Bay (Figure 1) on the Texas Gulf Coast is a large, highly productive and economically important environmental system. The Bay encompasses over 500 square miles in surface area and is very shallow with an average depth of approximately 6 feet and a maximum depth of 10 feet except in dredged channels.

Various estimates claim that from 60 to 90% of the aquatic life on the Texas Gulf Coast spends some time of its life cycle either in or dependent upon Galveston Bay. A substantial commercial fishing industry harvests shellfish including crab, shrimp and oysters, and a variety of fin fish. The Bay provides substantial recreation benefits including boating, swimming and fishing.

The Bay is of great importance for the shipping which connects Houston, Texas City, Galveston and other minor ports with the trade centers of the world. Houston presently is the nation's third largest port.

The Houston Ship Channel is a dredged channel which traverses a distance of 55 miles from outside Galveston Island through Galveston Bay and inland to the port of Houston. In its upper 25 miles the deep draft waterway is an environmental modification of Buffalo Bayou and the San Jacinto River. The banks of the channel are broken by 12 bayous, the San Jacinto River, several tidal flats and small shallow bays. The upper channel with reference mile points is shown in Figure 2. First modifications of the system originated in March 1905, when channel bends were

widened and pile dikes constructed along the channel. Dredging work on the channel began in 1906 when the city of Houston started developing a 16 foot deep channel. The turning basin and the slips at Houston were excavated between December 1906 and May 1910.

Two years later, in 1912, a contract was made to provide a 25 foot channel from the Gulf, across 25 miles of fast shoaling Galveston Bay and 30 miles through Buffalo Bayou, to the turning basin. This contract required that the entire 55 miles of channel, in full specified width and depth, be turned over at one time to the United States Army Corps of Engineers. In the years from 1919 to 1925, the waterway was deepened to 30 feet, widened, and the Houston Turning Basin enlarged. Bends were realigned and the inland portion of the channel from Morgan's Point to Baytown was widened during the period from 1930 to 1935. The main channel was widened and the depth was lowered to 34 feet in the 1935-1945 period. After 1945, further widening of the channel was carried out until 1948. In 1948, a ten year deepening and widening project was initiated, which called for a channel 36 feet deep. In 1958 and 1959, the channel depth was increased to 40 feet in all sections except that portion of the waterway from Sims Bayou to the Turning Basin. Since 1960, Corps of Engineers sponsored improvements have included realignment of bends, and depth increases to 42 feet in the lower reaches of the waterway. Today, the bottom width of the channel ranges from 150 feet in the Houston Turning Basin to 1000 feet at some locations along the channel.

Since the end of World War II, the Houston Ship Channel industrial complex has undergone tremendous expansion, and as a result, the channel now receives heavy pollution loadings comprised of both domestic and

industrial wastes. These heavy waste loads together with the sluggish flow characteristics of the waterway have over-loaded the natural purification capability of the estuary resulting in a severe pollution problem.

Many of the major ship channel industries and their products are shown in Figure 3.

The Houston Ship Channel has served as the receiving water for the waste materials from the Houston metropolitan area and its tremendous industrial complex. The location of the major industrial and domestic waste sources are shown in Figures 2 and 3.

The effect of these wastes in the degradation of the water quality has been magnified by the predominant physical features of flow, tide and salinity.

Flow statistics for the upper Houston Ship Channel are shown in Figure 4. In 10% of the months the flow is 100 cubic feet per second or less. In only half of the months does the flow exceed 430 cfs. Thus waste materials remain in the channel for an average of 43 days.

The tidal range on the Gulf Coast is only on the order of one foot. This low tidal exchange minimized diffusion, flushing and natural reaeration. The system is saline with salinities ranging from almost none to as high as 25 ppt in the upper reaches as a function of flow and turbulence. Both homogeneous and highly stratified vertical salinity gradients are observed.

Almost every classical form of pollution may be observed in the channel. Readily observable pollution is often observable as demonstrated in Figure 5.

Bacteriological contamination occurs from poorly treated domestic sources. Figure 6 shows coliform levels in the upper ship channel. If two gallons of this water were mixed into a 20,000 gallon home or apartment swimming pool, the bacterial quality would be degraded below acceptable swimming water standards.

Much of Galveston Bay is closed to oyster harvesting because of poor bacterial quality.

Oxygen demanding organics are discharged into the channel in such magnitude as to overpower the oxygen replacement capability of the channel. As of 1968, the loading approached 500,000 pounds per day, expressed as ultimate BOD (biochemical oxygen demand); or in lay terms, this would equal the raw sewage load of 3 million people or be approximately equal to 500,000 pounds of sugar per day.

Recent improvements have reduced this combined domestic waste, industrial waste and urban runoff load to about 250,000 pounds per day of ultimate BOD. The effect of this loading is shown in Figure 7. In each month of the year, no dissolved oxygen is found in the upper 16 miles of the channel. Only in the bottom few miles do oxygen levels exist that can occasionally support aquatic life.

Analytical models developed by Texas A&M University estimate waste load reductions to a level of 25,000 - 50,000 lbs/day (BOD_5) are required during the different months of the year to maintain minimum dissolved oxygen levels.

Since present economical waste treatment technology cannot meet these levels, new concepts including in-channel aeration are being investigated.

Nutrients have not been thoroughly studied, but problems are expected from the present and future high levels and substantial algae blooms are periodically observed in upper Galveston Bay.

Periodic oil slicks are noted in the channel as a result of spillage from vessel loading operations and from industrial discharges.

Sediment materials build up in the channel at the rate of from two to four feet per year. These sediments are a combination of silt which washes from the urban areas and organic sludge components.

Research at Texas A&M University has shown that 32% of the organic waste discharge becomes entrapped in the bottom sediments. Some 20,000 acre feet per year of this black greasy-looking anaerobic sludge remains on the bottom of the channel until periodically dredged.

Studies are just now underway to adequately evaluate the hazardous materials discharged into the Houston Ship Channel. Pesticides, pesticide manufacturing residues, heavy metals and other materials are known to be present.

The recent case involving the daily discharge of cyanide emphasizes the toxic material problems.

The net result of the waste materials discharged to the channel is demonstrated by the list of fish kills compiled by a Texas A&M University research staff member. Low dissolved oxygen in combination with stress caused by toxic ions is believed to be the predominant cause of death. Reported fish kills in the Houston Ship Channel area are listed in Table 1.

There is hope for the future. Galveston Bay is not yet a dead system, and the Houston Ship Channel pollution load trend has been reversed.

TABLE 1 REPORTED FISH KILLS - HOUSTON SHIP CHANNEL AREA

DATE	LOCATION	ESTIMATED #KILLED	ESTIMATED #SPECIES	PROBABLE CAUSE	DATA SOURCE
26 June 1960	Morgan Point	large #	10	N. A. *	Parks & Wildlife
23 Aug 1960	" "	N. A.	7	"	"
21 Oct 1960	" "	"	N. A.	"	"
May 1963	San Jacinto Bay	"	"	"	"
Sept 1963	Scott's Bay	"	"	"	"
July 1964	Burnett Bay	"	"	"	"
Sept 1964	Scott's Bay	"	"	"	"
Aug 1965	HSC	5,000	"	Low D. O.**	"
Sept 1965	Morgan Point	N. A.	"	"	"
Sept 1965	San Jacinto Bay	5,000	"	"	"
Aug 1967	" " "	N. A.	"	unknown	"
Sept 1967	HSC	"	"	Low D.O.	"
6 Sept 1968	A&M Mile 0-4	5,000 - 10,000	N. A.	See table 2	"
10 Sept 1968	Morgan Point	30,000	5% game	See table 2	P&W, FWPCA*** Parmer
18 Sept 1968	Scott's Bay A&M 2-4	1,000	10% game 50% comm.	"	" " "
20 Sept 1968	A&M Mile 4	100-500	2-3	"	Parmer
7 Oct 1968	Morgan Point	100	N.A.	"	"
15 Nov 1968	A&M Mile 16	50-100	1-2	"	"
26 Nov 1968	Morgan Point	50-100	1-2	"	"
24 Dec 1968	A&M Mile 12	25-50	1-2	"	"
5 Apr 1969	A&M Mile 4	100	3-5	See table 2	"
22 Apr 1969	" " 10	500-1,000	2-3	"	"
24 Apr 1969	" " 6-3 SJR	1,000-5,000	2	"	"
5 May 1969	Mouth SJR	5,000	3-5	"	"
8 May 1969	A&M Mile 4-10	10,000-20,000	5-10	"	"
20 May 1969	" " 0-16	" "	"	"	"
6 June 1969	" " 4	100	1-3	"	"
11 July 1969	" " 4-12	"	"	"	"
12 July 1969	" " 2-10	1,000-5,000	5-10	"	"
4 Sept 1969	Scott's Bay	5,000	3-5	"	"
Feb 1970	Barbour's Cut	50-100	1-2	N. A.	"
2 May 1970	A&M Mile 4	1,000	1-3	"	"
4 May 1970	" " 4-6	2,000	?	"	"
6 May 1970	" " 10-12	2,000	3-5	"	"
17 May 1970	" " 4-10	50-100	1-3	"	"
19 May 1970	" " 4	0-50	1-3	"	"

*Information Not Available

** Dissolved Oxygen

*** Federal Water Pollution Control Administration

NOT REPRODUCIBLE

Federal involvement, expanded state capability and action, expanded research programs and public concern are beginning to swing the pendulum to a more proper direction.

The Environmental Engineering Division of Texas A&M University's Civil Engineering Department has carried out a vigorous program of research relating to the Houston Ship Channel. Currently a staff of 40 supported by a field laboratory and a well equipped three vessel research fleet is involved.

This research, coupled with those of companion groups and effective state and federal programs, shows promise in making the Houston Ship Channel-Galveston Bay System an acceptable aquatic environmental system.

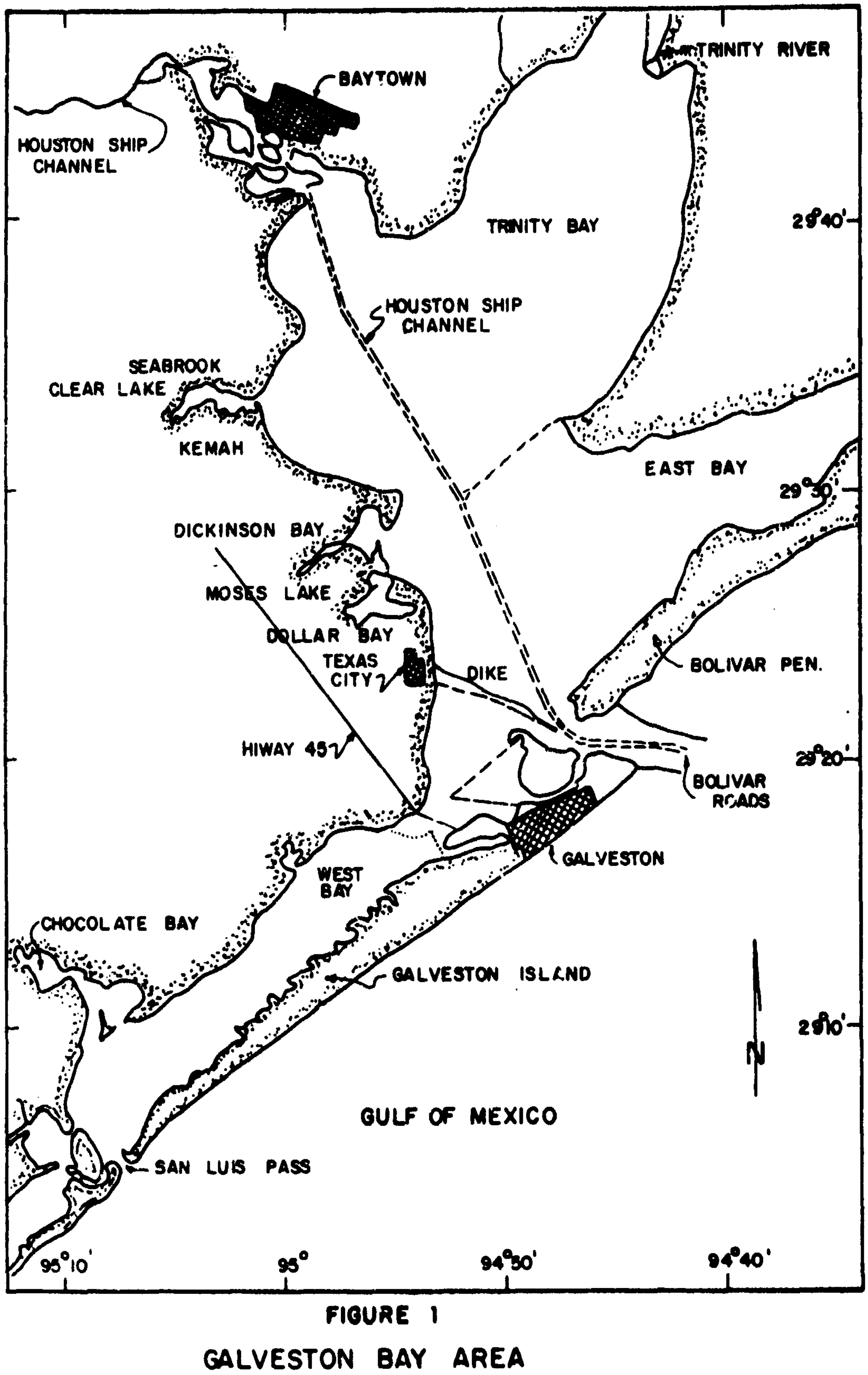


FIGURE 1

GALVESTON BAY AREA

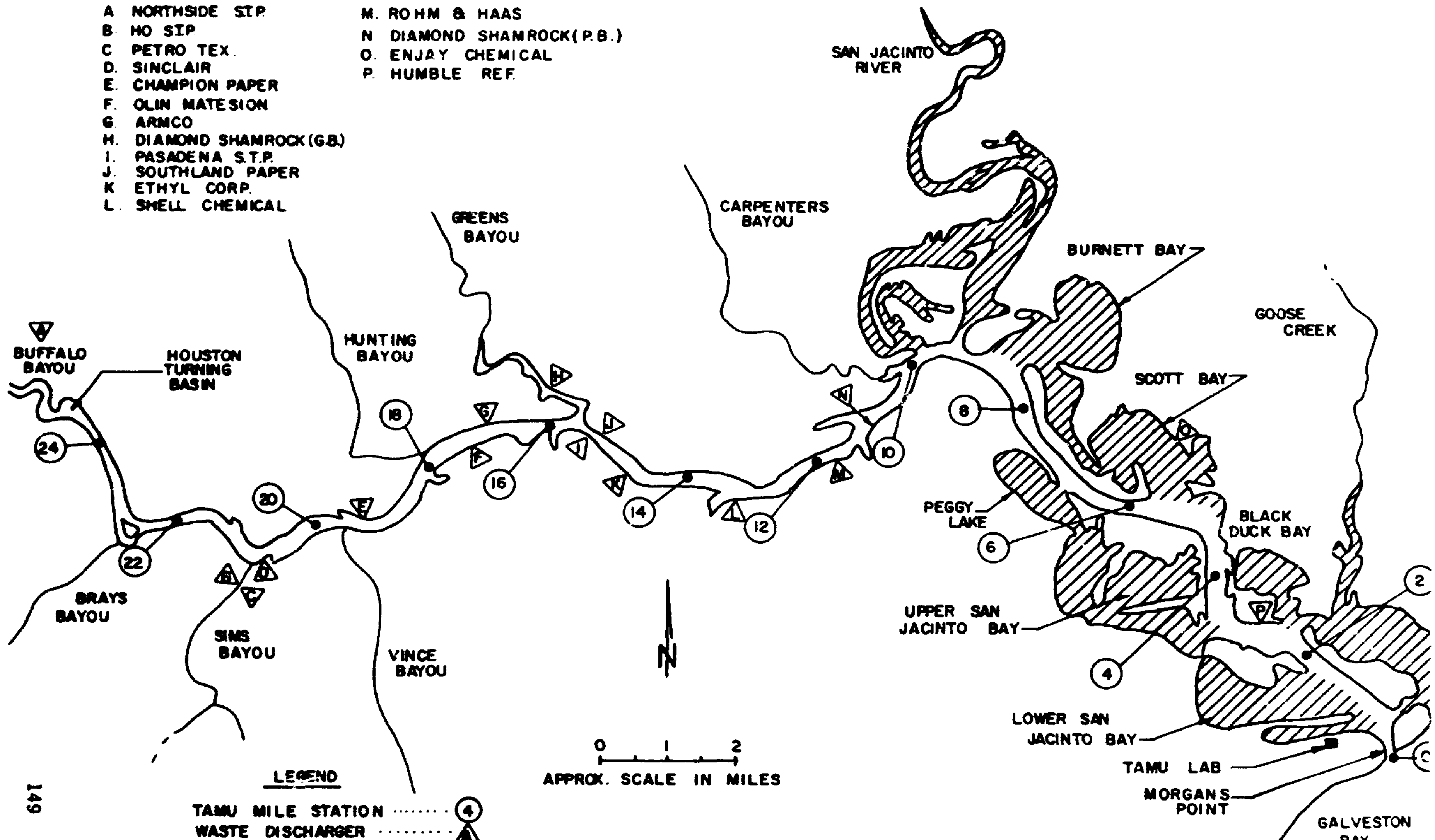


FIGURE 2

LOCATION OF DOMESTIC AND INDUSTRIAL DISCHARGES ON THE HOUSTON SHIP CHANNEL

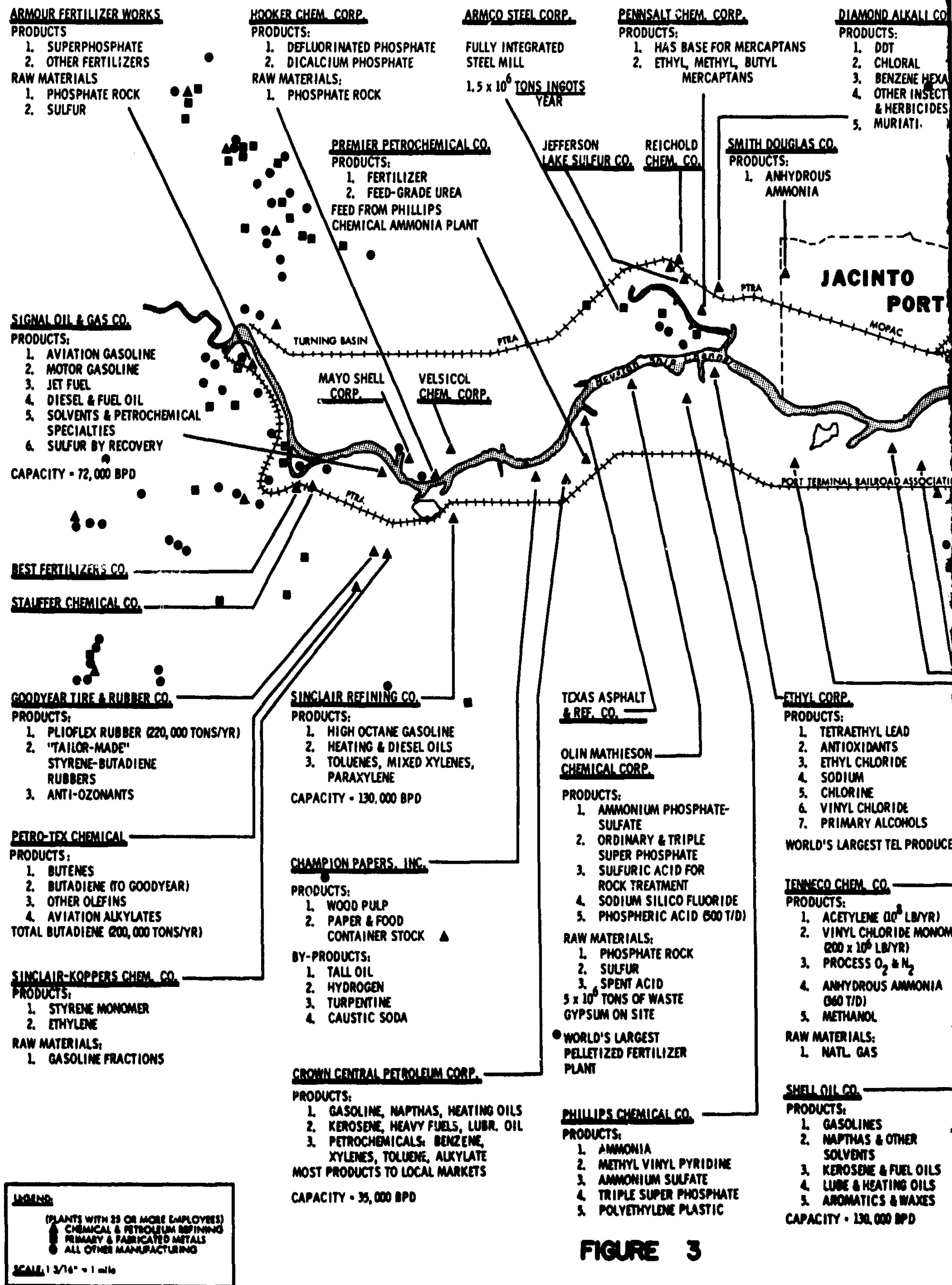
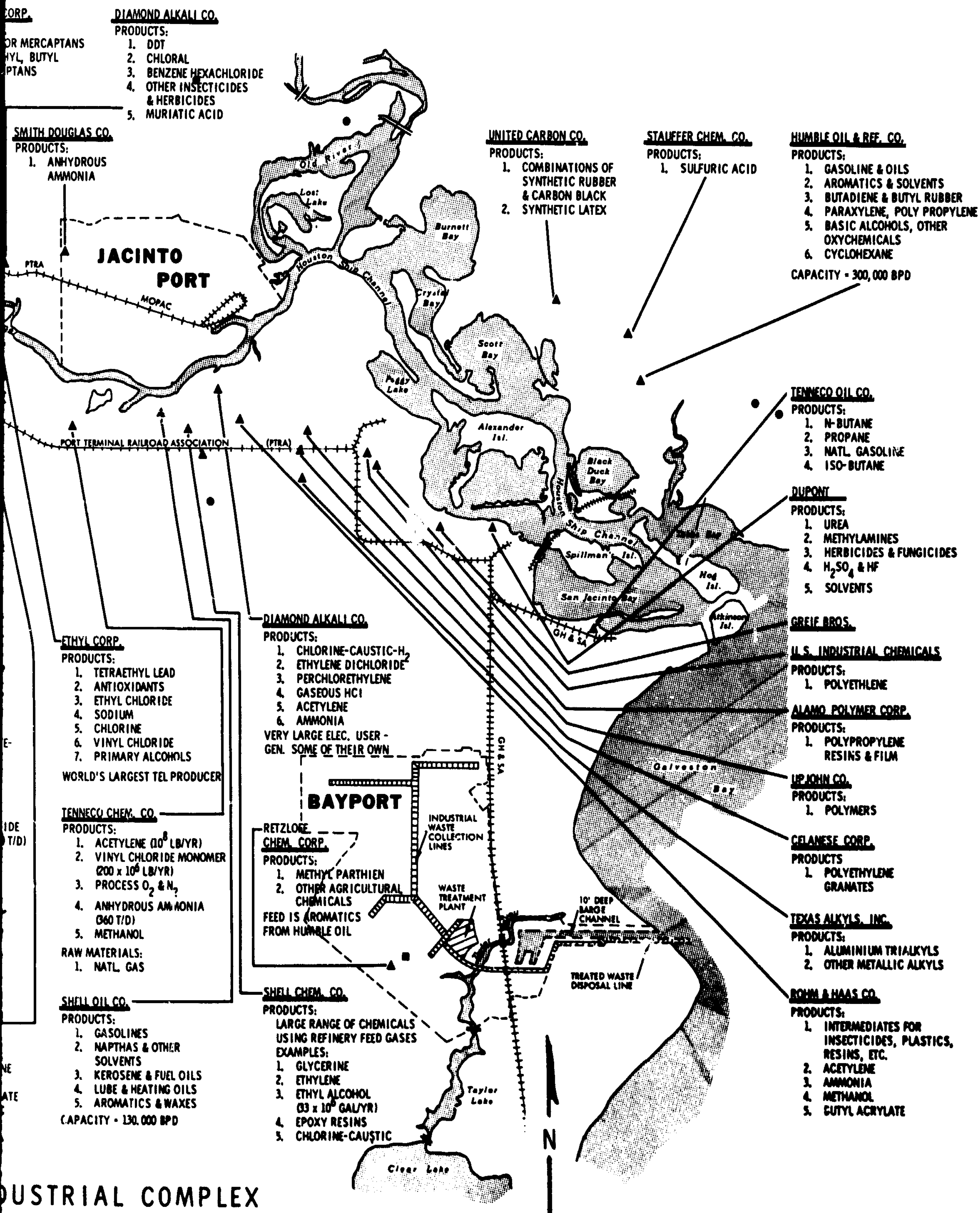


FIGURE 3

HOUSTON SHIP CHANNEL INDUSTRIAL COMP



USTRIAL COMPLEX

Map Courtesy of

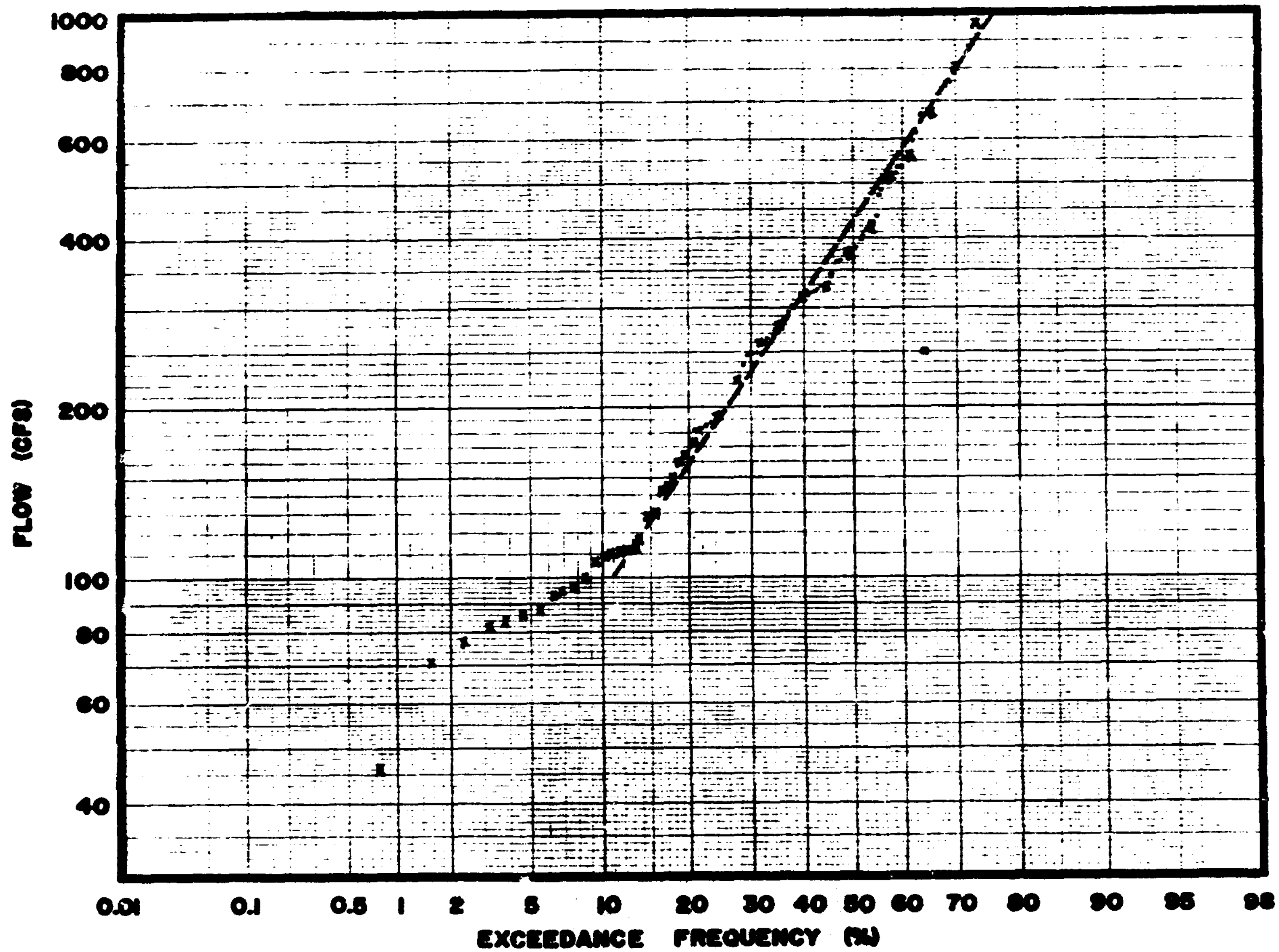


FIGURE 4

FLOW DURATION CURVE—HOUSTON SHIP CHANNEL ABOVE SAN JACINTO RIVER
—EXCLUDING WASTE INFLOWS TO CHANNEL—

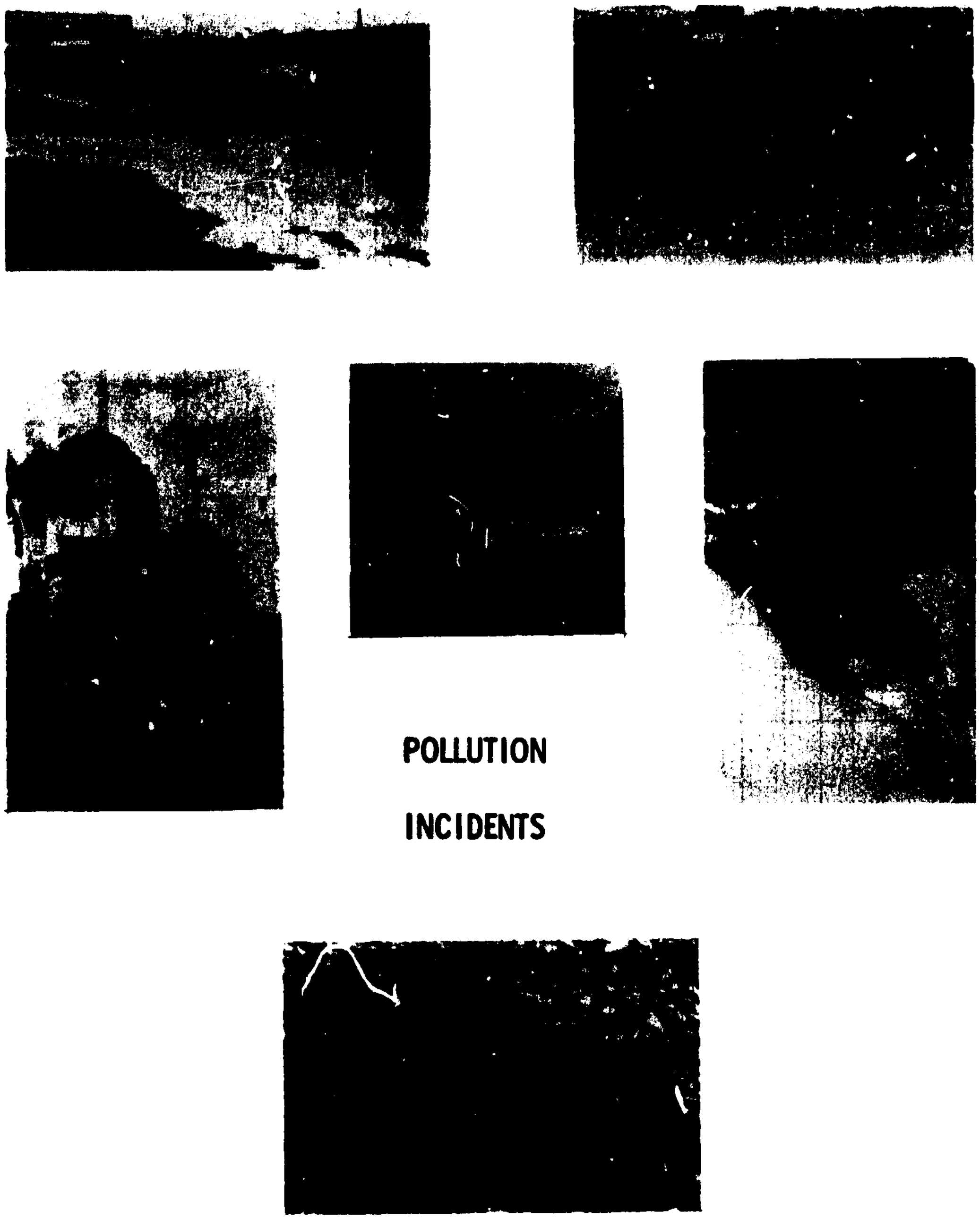


FIGURE 5

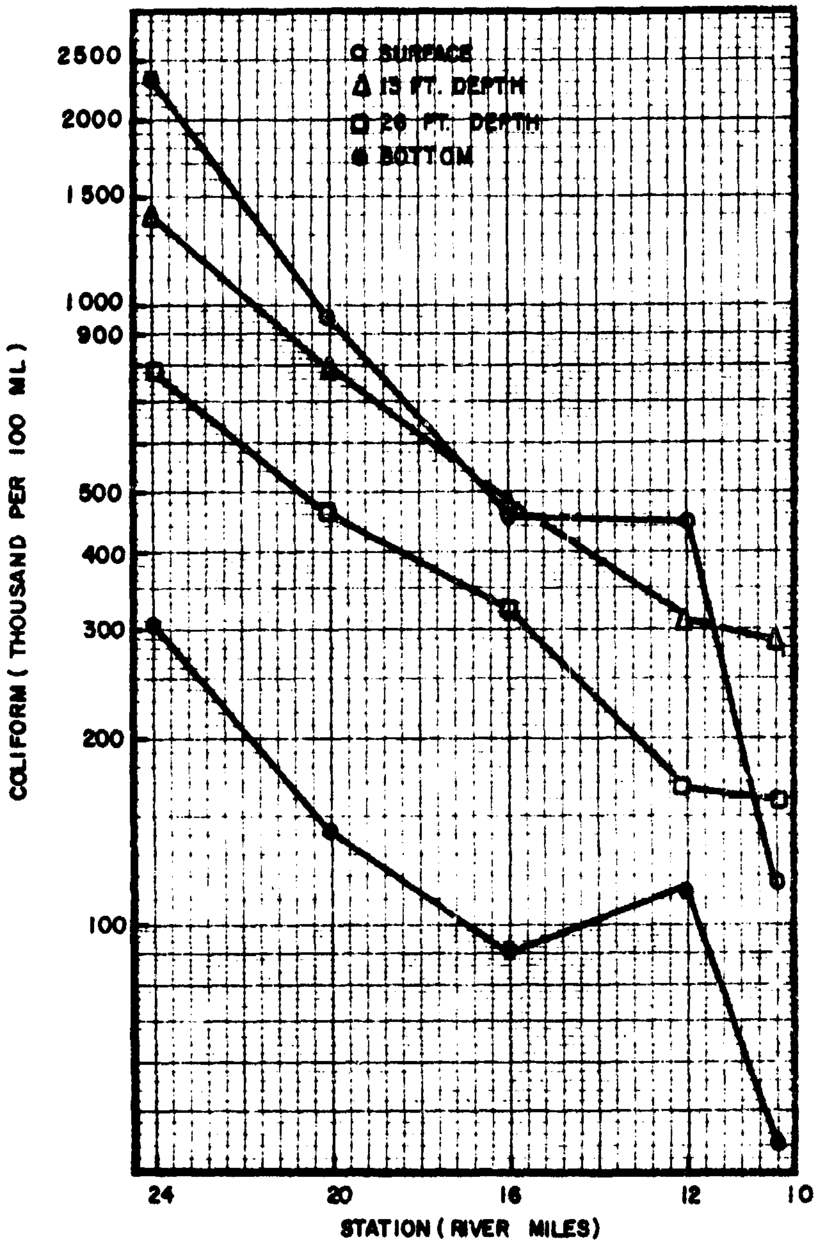


FIGURE 6

AVERAGE YEARLY COLIFORM COUNT PROFILE FOR THE UPPER HOUSTON SHIP CHANNEL

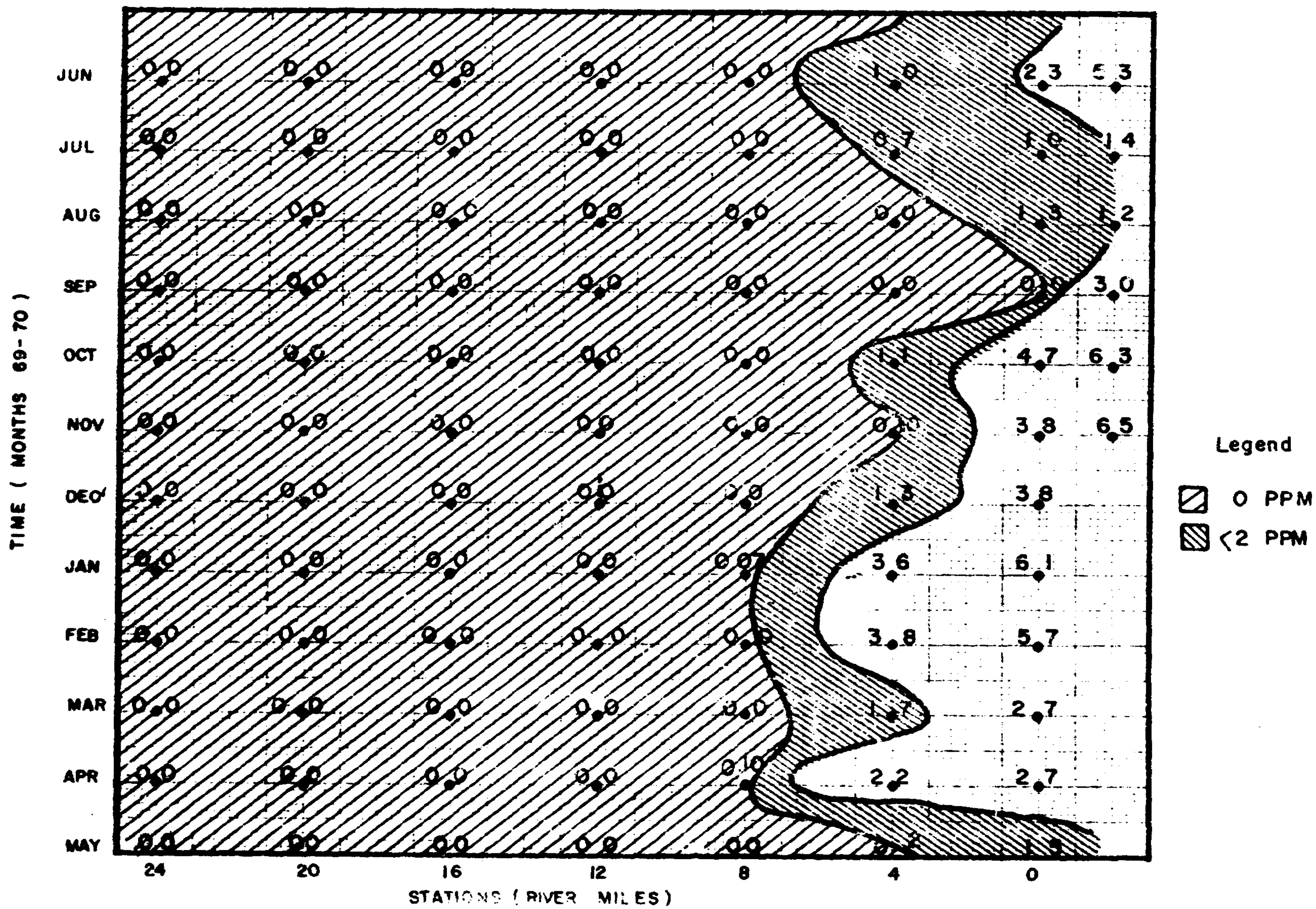


FIGURE 7

SUMMARY OF DISSOLVED OXYGEN (MG/L) HOUSTON SHIP CHANNEL

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COMMITTEE ON HAZARDOUS MATERIALS
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July 1, 1971

COMMITTEE ON HAZARDOUS MATERIALS

In response to a letter of December 5, 1963 from the Commandant of the U.S.Coast Guard to the President of the National Academy of Sciences, a committee has been established in the Division of Chemistry and Chemical Technology with the following purpose.

The NRC Committee on Hazardous Materials is a committee of the National Academy of Sciences - National Research Council charged to advise the Coast Guard on scientific and technical questions relating to safe maritime transportation of hazardous materials. The need for such a committee has been occasioned by the rapid growth of chemical industry during recent years, coupled with major advances in shipping technology. A wide variety of materials that are combustible, toxic, or chemically reactive are now being shipped in bulk over congested waterways and additional materials are in prospect. The methods of shipping include pressure containers (e.g., for compressed gases), cryogenic containers (for liquefied gases including LNG and LPG), and heated containers (for liquid sulfur and liquid asphalt), as well as the more conventional means. The function of the committee is to visualize the problems created in regard to safety and public health, and to formulate research or engineering approaches to their solution. As the outcome of such studies, the committee will make recommendations that the Coast Guard can consider in discharging its own regulatory responsibilities.

Membership of the committee for Fiscal Year 1971-1972:

Donald L. Katz, Chairman
University of Michigan

Robert B. Beckmann
University of Maryland

David Burgess
Bureau of Mines

Homer W. Carhart
Naval Research Laboratory

W. A. Cunningham
University of Texas

W. Doyle
Factory Insurance Assoc.

Roy W. Hann
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B. L. Harris
Edgewood Arsenal, Maryland

Clyde McKinley
Air Products and Chemicals, Inc.

W. E. McConnaughey
Liaison with the U. S. Coast Guard

Howard H. Fawcett, Technical Secretary
NAS-NRC

SENIOR ADVISORY PANEL

The Committee on Hazardous Materials has enjoyed association with several members who have served with distinction. Each has made significant contributions to the understanding of the technical aspects of hazardous materials in bulk water transportation, generating and developing concepts which are useful to the U. S. Coast Guard. It would be unfortunate if these distinguished Committee members completely severed their relationship with Committee Activities upon completing a tour of service.

Therefore, a Senior Advisory Panel has been established to recognize contributions of these individuals, and to provide a mechanism for continued limited service. By this assignment, the Committee will retain a valued resource in expertise and experience.

Several persons, who have not taken part in the full deliberations of the Committee membership, nevertheless have made outstanding contributions to the various panel studies. We feel it is fitting and proper that their distinguished service also be recognized. Accordingly, these individuals are invited to membership on the Senior Advisory Panel.

Membership on the Panel is normally for a period of three years, subject to reappointment with mutual continued interest and service.

Panel members appointed July 1, 1970:

*Dr. Glenn H. Damon
*Prof. C. Sliepcevich
*Miles E. Woodworth
Prof. James Brown
Prof. Adrian Gaufin
Dr. R. H. Van Dolah

Panel members appointed July 1, 1971:

**Edgar M. Adams
**Dr. W. W. Crouch
***Dr. Joseph H. Padon

* Committee Member 1964-1970
**Committee Member 1964-1971
***Committee Member 1965-1971

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